CONTRACT REPORT C-71-1

LATEX MODIFICATION OF FAST-FIX C-1 CEMENT FOR THE RAPID REPAIR OF BOMB-DAMAGED RUNWAYS

by

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May 1971

Sponsored by U. S. Air Force, Wright-Patterson Air Force Base

Conducted for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Under Contract No. DACA 39-70-C-0022

By The Dow Chemical Company, Midland, Michigan

ARMY-MRC VICKSBURG, MISS

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FOREWORD

The work described in this report was accomplished by The Dow Chemical Company of Midland, Michigan, under Contract Number DACA 39-70-C-0022 for the U. S. Army Engineer Waterways Experiment Station (WES). The work was sponsored by the Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This report summarizes work conducted from 16 April 1970 through 12 May 1971. Mr. R. Douglas Eash was the Principal Investigator and Technical Specialist for the project. Mr. G. M. Hart conducted the literature search and review. Mr. Eash and Mr. Hart prepared this report.

The assistance and guidance of Mr. James M. Polatty, Chief, Engineers Mechanics Branch, Concrete Division, WES, are gratefully acknowledged.

The contract was monitored by Mr. Polatty. Contracting Officer was Col. Levi A. Brown, succeeded by Col. E. D. Peixotto, Director WES. Technical Director was Mr. F. R. Brown.

ABSTRACT

This report consists, essentially, of two parts: a state-of-the-art review and laboratory testing of the effects of adding two Dow polymeric latexes to "Fast-Fix C-1".

The state-of-the-art review covers several basic studies in which many materials, both organic and inorganic, were investigated for the rapid repair of damaged runways. The study was then focused on: (1) the study of fast-setting inorganic cements, such as calcium sulfates (which include Fast-Fix C-1), high aluminum cements, and silico-phosphate cements; and methods to obtain fast setting, such as very fine grinding of the cement clinker and the use of organic, inorganic, and thermal acceleration. Miscellaneous cement technology; such as methods to obtain high strength concrete, silicate concrete, and cementitious ceramic materials, are also covered.

The state-of-the-art review also has a section on "Roads, Runways, Compacted Areas, and Soil Stabilization" in order to indicate areas in which fast-setting cements can serve and the requirements placed on this service. Topics covered are runway design, pavement requirements, pavement evaluation, surface repair, and cold weather construction. "Lessons-Learned" in South Vietnam are reviewed to show utility for fast repair materials.

In the laboratory study two polymeric latexes, Dow Latex 460 and Dow Latex 464, were incorporated at selected concentrations in Fast-Fix C-1 mortars. Laboratory tests were conducted to determine freeze-thaw durability, tensile strength, compressive strength, flexural strength,

and shear bond. All latex concentrations improved bond strength to concrete and freeze-thaw durability. All latex concentrations decreased 24-hour water absorption. All latex concentrations tended to retard set and early strength gain. Low concentrations (4 percent) of Latex 464, however, produced a modest improvement in compressive and flexural strengths, but no change in the elastic modulus.

Due to the added expense and more complicated mixing procedure, the use of latexes to modify Fast-Fix C-1 cement for the Rapid Repair of Bomb-Damaged Runways is not recommended.

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I. INTRODUCTION

Considerable effort has been expended by the Air Force and allied services and by civilian organizations, under contract to these services, to develop capabilities for the rapid repair of mortar-, rocket-, or bomb-damaged runways. Among the materials which have been evaluated are thermoplastic resins; thermosetting resins; plastic foams; fast-setting cements; asphaltics; metal landing mats; compacted, graded aggregate; and sulfur. Concomitant with material research was research to develop equipment for high speed mixing and application of the more promising materials. The solution of interest here was a series of fast-setting cements, developed by The Western Company of North America, containing high percentages of various gypsum semihydrates made by the U. S. Gypsum Company. These cements are produced under the "Fast-Fix" trademark, the one of greatest present interest being known as "Fast-Fix C-1."

Fast-Fix admirably fills the need in terms of rapid repair. There is, however, always room for improvement in performance: increased strength so as to reduce the quantity of material required; improved bonding to the existing runway; better resistance to traffic; less degradation by weather, fuel spills, jet blasts, etc. The Dow Chemical Company had developed polymeric latexes which, when added to portland cement mortars, so increased the strength and adhesiveness of the mortars that: (1) brick wall panels only one-half thickness of conventional masonry walls could be prefabricated, cured and lifted into place with one-half inch L-bolts inserted into the top three courses[E13,E14,E15]; and (2) concrete bridge decks can be resurfaced with a thin, long wearing coating[E16]. This study, then, was undertaken

to test two commercial forms of these latexes to see if they would improve Fast-Fix mortars as markedly as they improve portland cement mortars.

In order that we might have a comprehensive feel for the total subject of rapid repair of bomb-damaged runways, a "state-of-the-art review" was included in the study plan.

II. SUMMARY

A. GENERAL

Fast-Fix C-1 cement was developed by The Western Company for the rapid repair of bomb-damaged runways. Based on the structural properties of the cured cement, the repaired section must be about 11 inches thick to be able to support the wheel load of military airplanes. The additional requirement of the U. S. Air Force that the damaged area be repaired in one hour dictates the need of placement equipment capable of mixing and pumping material at the rate of 900 gallons per minute. This can be accomplished by one large machine or three smaller machines with the capacity of 300 gallons per minute.

If the structural properties of the Fast-Fix C-1 concrete could be appreciably increased, the thickness of the slab could be reduced resulting in lower pumping rates and in reduced quantities of materials needed to repair the concrete slab.

It is well established that latexes can greatly increase the structural properties of portland cement mortars and concrete. The object of the laboratory evaluation program is to determine if latexes produced by The Dow Chemical Company for the modification of portland cement systems will also have the same beneficial effect when used to modify Fast-Fix C-1 cement.

A second objective of this work is to conduct a literature survey to determine the state-of-the-art in the area of rapid setting early strength cements and concrete.

B. LITERATURE REVIEW

The literature review pertaining to information on the rapid repair of bomb-damaged runways, structural requirements of runway slabs and information on rapid setting cements is listed in Section III of this report. The Table of Contents provides an excellent summary of the topics covered in this survey.

C. LABORATORY TEST PROGRAM

Latex Modified Fast-Fix C-1 cement formulations were prepared, cured and tested for compressive, tensile, flexural, and bond strength and for freeze-thaw durability. The results of this program are detailed in Section IV of this report.

Dow Latex 460 and 464 greatly improve the freeze-thaw resistance and the bond strength of Fast-Fix C-1 cement. The higher the latex content, the better the bond strength and freeze-thaw durability. In addition, increasing latex levels decrease the 24-hour water absorption properties of the Fast-Fix C-1 cement.

Both latexes slightly reduce the set time of the cement and slightly reduce the one hour strength properties.

Dow Latex 460 does not improve the compressive, tensile or flexural strength properties of Fast-Fix C-1 cement, nor does Dow Latex 464 at the 15 or 20 percent level. However, Dow Latex 464 produces a modest increase in the compressive and flexural strength of Fast-Fix C-1 cement after 28 days cure.

D. CONCLUSION

Dow Latex 460 and Dow Latex 464 are not recommended for the modification of Fast-Fix C-1 for the Rapid Repair of Bomb-Damaged Runways except in areas where improved freeze-thaw resistance is a major factor. The added expense and more complicated mixing procedures are not justified by the modest structural improvements obtained from the use of Dow Latex 464.

The latex modification of Fast-Fix C-1 for the repair of surface damage to structurally sound concrete could be useful due to the increased bond strength resulting from the latex modification. Where the speed of repair of this type of failure is not a factor, a latex modified portland cement system would be more economical and probably more permanent in nature.

III. LITERATURE REVIEW

A. TYPE AND SOURCE

1. Type of Information Desired. In order to better grasp the ultimate problem - "The Rapid Repair of Bomb-Damaged Runways," it was decided that information on two broad topics should be obtained: (a) the requirements for construction and repair of airport slabs, and (b) the properties of commercially available rapid setting cements with special emphasis on Fast-Fix.

a. Requirements for runway slabs. Base, subbase and subgrade bearing strengths; physical strengths depending on aggregate-cement-mix water combinations influence the slab thickness required. Endurance, or weatherability, of a runway depends on resistance to jet fuel, gasoline, battery acid, deicing chemicals, water, freezing and thawing, fumes, jet blast, etc.

b. Information on rapid setting cements. A short search of the literature soon reviews a large number of chemicals and techniques to accelerate the cure of standard cements. The type of information desired was trade name, composition, cost, setting times and strengths at set periods such as 30 minutes and 1 hour, chemical resistance, weatherability, equipment needed for mixing and application, the effect of additives, and adhesion of recommended mixes to in-place slabs.

2. Literature Sources Considered and Searched. A very cursory search soon reveals how voluminous even small segments of the cement literature can be. A whole volume[D2] was read which discusses only "High-Alumina

Cements and Concretes." Each of the eight chapters in that book has extensive literature references. The Highway Research Board publishes an annotated bibliography "Admixtures for Highway Concrete"(D4) which for the period before 1963 has 447 references on air-entraining admixtures, 461 references on accelerating admixtures, and 86 references on water-reducing and set-retarding admixtures. Almost any technical article has its appended bibliography - reference A2, one of several with the title "Rapid Repair of Bomb-Damaged Runways," has 42. One can, thus, quickly obtain pertinent literature references in far greater numbers than he can digest in a reasonably limited period of time and must make some selection.

At the beginning of this study contract, we proposed certain "sources" to search for information; the Project Monitor suggested others. This section presents these sources and an indication of the type of services available. Table I shows a listing of "Suggested Subject Headings for Literature Search" sent to the respective technology centers.

a. Bryant Mather, Director
   Concrete Technology Information Analysis Center (CTIAC)
   Department of the Army
   Waterways Experiment Station (WES), Corps of Engineers
   Vicksburg, Mississippi 39180

A very comprehensive "Fast Setting Cement Literature Survey" was prepared by Clara F. Derrington, Research Chemist, Chemistry and Plastics Section, Engineering Science Branch, Concrete Division, WES, for CTIAC. This well written report not only summarized work on fast-setting cements and accelerating additives, bit was accompanied by the cited literature references.

TABLE I

SUGGESTED HEADINGS FOR LITERATURE SEARCH

I. Bomb-Damaged Runways, Repair of

II. Early-Strength Cements and Concretes
   1. Fast-setting Cements and Concretes
   2. Fast-hardening Cements and Concretes
   3. Aluminate (Alumina, Aluminous) Cements
   4. Gypsum Cements
   5. "Fast-Fix"
   6. "Regulated Set" (Jetset)
   7. "Florok Anchor Grout"
   8. "Mari-Crete"
   9. "Ciment Fondu", "Lumnite" - Etc.

III. Accelerating Admixtures (Accelerators)

IV. Permanence or Weatherability Requirements for Runways
   1. Fuel, Oil, Etc. Effects (jet fuel, gasoline, battery acid)
   2. Freezing and Thawing (frost action)
   3. Runway Maintenance (general)
      a. Snow and Ice Control
      b. Chemicals and Abrasives
      c. De-icing Chlorides

b. Defense Supply Agency
Defense Documentation Center (DDC)
Cameron Station
Alexandria, Virginia 22314

"DDC is the central facility within the Department of Defense for processing and supplying scientific and technical reports of Defense sponsored research, development, test and evaluation efforts....User organizations may request "report bibliographies".... Upon receipt of request, DDC will make a computer search of the collection to locate those technical reports most pertinent to user's research problem or project... Requesting organization specifies the time coverage of search - 6 months, 1 year, 3 years, etc. User describes his research problem, project or other subject interest in his own words...DDC converts description to its computer language for processing.... Resultant bibliography is sent to user in the form of a bound document... Each page contains a description of a single document to enable user to determine its pertinence to his current efforts....Copies of documents desired are then requested by using DDC Forms 1."

Pamphlet DSAM 4185.3, "Registration for Scientific and Technical Information Services of the Department of Defense," which a user needs to obtain, lists some 23 other Information Analysis Centers from which various types of information may be requested.

c. National Aeronautics and Space Administration (NASA)
Scientific and Technical Information Division
Post Office Box 33
College Park, Maryland 20740

The "NASA Literature Search is based on a computer search of the collection of bibliographic and indexing information stored on magnetic tapes at the NASA Scientific

and Technical Information Facility." There are normally three references per page giving titles, authors, and index terms. We received 83 citations from 1964 to date under the search title, "Repair of Runways," and ordered seven of them. The NASA literature search also covers literature compiled by the American Institute of Aeronautics and Astronautics.

d. American Concrete Institute (ACI)
Publications Department
Rexford Station, Box 4754
Detroit, Michigan 48219

"ACI Publications as of November, 1969" lists available literature. Some recommended articles with their order codes are: 57-7, "Repair of Concrete Pavement;" 60-3, "Performance of Bonded Concrete Overlays;" 60-64, "Admixtures for Concrete" by ACI Committee 212; M-3, "Freezing and Thawing of Concrete: Mechanism and Control;" 50-20, "Effect of Age of Concrete on its Resistance to Scaling Caused by Using Calcium Chloride for Ice Removal;" 617-58, "Specifications for Concrete Pavements, and Concrete Bases;" 63-62, "Properties of Cement Mortars Modified by Polymer Emulsion."

e. A. B. Mobley, Manager
Highway Research Information Service (HRIS)
Highway Research Council
2101 Constitution Avenue
Washington, D. C. 20418

Several annotated bibliographies prepared by HRIS were on hand: "Admixtures for Highway Concrete," 1965; "Recent Russian Research on Cement and Concrete," 1964; Bibliography 13, "Calcium Chloride in Concrete," 1952; and Bibliography 32, "Curing of Concrete," 1925-1960. We also had a copy of "Publications (January 1970)." In reply to our letter requesting information, it was

estimated that a computer file search for the information that we desired would cost between $80.00 and $100.00. This search was not requested. Several enclosures with the received reply indicated that HRIS would be a recommended source for a more complete study, e.g., "Pavement Patching Techniques and Materials" - a survey of practices of other states and authorities by Division of Research and Evaluation, New Jersey Department of Transportation (November 1969), Project 7742-519; "The Use of Aluminous Cements for the Installation or Rapid Repair of Runways and Other Paved Structures," HRIS Document Record (2/26/69) 2R 40 063224 (two references are cited); "A Quick Setting Silico-Phosphate Cement" HRIS Document Record (11/18/69) 2R 32 208159 (one reference is to an active project by the Bureau of Public Roads with an estimated completion date of December 1971).

f. N. F. Somes, Structural Research Engineer
Structures Section, Building Research
Division, IAT
U. S. Department of Commerce
National Bureau of Standards
Washington, D. C. 20234

Their reply to our letter was that The Structures Section has not compiled literature pertinent to the subject of fast-setting cements. Sources recommended were: Highway Research Board for information on accelerating admixtures; Portland Cement Association, "Regulated Set" cement; Universal Atlas Company for their work with aluminate cements; California Highway Department, Corps of Engineers, and Sika Chemical Company for information on Fast-Fix C-1. Two recommended references to much literature on the subject are: "The Chemistry of Portland Cement" by R. M. Bogue, Reinhold Publishing Corporation, and "Comprehensive Bibliography of Cement and Concrete,

1925-1947" by F. O. Slate, Joint Highway Research Project, Engineering Station, Purdue University.

g. G. J. Verbeck, Director of Research
Research and Development Laboratories
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60076

No reply was received to our letter asking for information, and with all the other literature collected this source was not pursued. Others in our department had previously been in contact with Mr. Verbeck in regards to "Regulated Set" concrete and this information was already available.

h. M. H. Allen, P. E.
Director of Research
Structural Clay Products Institute (SCPI)
1750 Old Meadow Road
McLean, Virginia 22101

SCPI had developed "Quick-Set" grouts. They were inquiried for further data on this material.

i. R. J. Wenk, Gypsum Products Manager
United States Gypsum Company
1000 East Northwest Highway
Des Plaines, Illinois 60016

In reply to our inquiry, U. S. Gypsum informed us that if we desired their participation in our contract, that we should visit them at Des Plaines and discuss the magnitude of participation needed. Due to the amount of literature already collected and to time limitations, no further contacts were made with this source.

Chemical Abstracts (1957-1968), Engineering Index (1960-1970), and Applied Science and Technology Index (1960-1970) were searched under such terms as: air bases, military, runways; airports, runways; cement; concrete. A large number of potentially good references were noted, most of which, again due to time limitations, were not read.

k. Miscellaneous. Various proprietai ogress and Research Reports of The Dow Chemical Company we consulted. Periodicals and papers for the past severa years such as Journal of the American Concrete Institute; Engineering New Record; Building Research Station, Watford (England) "Current Papers," were reviewed.

B. REVIEW OF "RAPID REPAIR" MATERIALS AND TECHNIQUES

In the studies that have been made with titles indicating "rapid repair of bomb-damaged runways," "rapid site preparation," etc. (many of these are listed in Part A of the Bibliography), a large number of materials and techniques have been evaluated and a much larger number listed but not evaluated for various reasons. The quick-setting inorganic cements of which Fast-Fix C-1 is a member, will be mentioned here but treated in Part C of this Section III; the others will be reviewed here in Part B.

1. Repair Requirements.[A2,A11,A13] The objective of the "runway rapid-repair program" is to develop materials, equipment, and techniques to repair a crater in a runway created by a 750 lb bomb, exploding some 8 ft below the surface. It is necessary that this repair be accomplished in minimum time and be capable of supporting 16 passes of a 29,000 lb single, rolling wheel load, applied through a tire inflated to 300 psi. The maximum size crater resulting

from a 750 lb bomb is assumed to be 40 ft in diameter and 14 ft deep with peripheral damage to the runway surface for another 15 ft around the edge of the hole, giving a total damaged diameter of 70 ft. After backfill, the crater depth should be approximately 1 ft deep or about 3,900 cu ft in volume. The backfilled subbase is assumed to be poorly compacted soil with a CBR* of 4. In most studies, this backfilled crater is assumed and the problem is to supply a suitable "cap" or bearing surface working with the top 12 in. of fill.

Requirements put on this surfacing material is that it support the 29,000 lb rolling wheel load within 30 minutes after placement at ambient temperatures from -5°F to +110°F and at dry to wet humidity conditions. To meet these requirements, a flexural strength of 300 psi and a compressive strength of 1000 psi is assumed to be needed 30 minutes after pouring[A6].

The original runway surface will generally be concrete with some asphalt strips possible.

Application equipment should be the present Air Force Base Civil Engineering Equipment with the least possible auxiliary equipment or modifications for the new rapid cure techniques. Specialized equipment can be developed, though, if necessary.

*CBR = California Bearing Ratio. The CBR is a measure of the relative bearing capacity of soils and base materials. CBR is expressed as a percentage of the unit load required to force a 3 in.^{2} piston into the soil, divided by the unit load required to force the same size piston the same depth into a standard sample of crushed rock[C18]. A further treatment of CBR is made in Section III.E.7.

2. General Studies. Some groups surveyed a number of materials before making a specific recommendation. These studies will be summarized here.

a. Raven Industries Study (A11) (15 October 1964 to 3 September 1965

(1) Introduction. An outline of the problem was supplied to manufacturers of quick-setting materials of all chemical types. From 87 different companies, some 144 different materials were received. These materials fell into nine categories.

(2) Materials evaluated and some significant results

(a) Polyester resins - All materials that utilize polyester as the base of the group. A 3 in. layer of polyester bonded rock aggregate, reinforced with steel wire carried the required loadings. Polyester resins were the most promising materials for aggregate bonding since they have a wider latitude of mixing ratios and are easily adjustable to meet various ambient temperatures. Polyester resins were available that would cure in the presence of water but none were available that would displace or bond to a water film absorbed on the surface of a rock aggregate. On this basis it is necessary to dry aggregate and to store it in a dry condition near the repair site.

(b) Epoxy resins - All materials where the epoxy group enters into a curing system. Epoxy resins with their more exacting requirements for stoichiometric mixing ratios were very difficult to adjust to a wide range of curing temperatures.

(c) Thermoplastic materials - Materials ranging from waxes to special thermoplastic materials from various sources (Elvax 22, wax with 140°F softening point;

Cascomelt HA-5244). The very slow cool down and attendant gain in strength of thermoplastic type materials limits their usefulness in a rapid repair program. One material, poured at 325°F, was still at 135°F and not completely set one hour later, and was at 125°F two hours later.

(d) Inorganic binder - Cement, cementitious type materials and other inorganic setting materials (Cyanoloc 62, Speed Crete Mix No. 1, PorRok, portland cement Type I and Styrocrete 200, Anchor Sulfaset, Steel Rock, Lumnite Cement).

(e) Bituminous materials - Bituminous or asphaltic materials including aggregate blends.

(f) Urethanes - Covering both urethane elastomers and foam chemicals.

(g) Silicone rubber materials

(h) Phenolic resins - Including straight phenolic bonded sand and phenolic foams.

(i) Others - Not classifiable into the other groups (Pliopave 1-170).

(3) Summary. Before a completely useful rapid repair system could be developed, certain problems in the materials handling area need to be solved: (a) the development of a resin heating system that would bring resin stored at any ambient temperature up to the desired pumping or mixing temperature; (b) pumping equipment that could pump at 200 gallons per minute in a controllable and reproducible manner; (c) resin mixing or blending equipment compatible with the catalyst system required and capable of easy variation to adjust to ambient conditions. As mentioned in the preceding paragraph [(2)(a)], polyester resin plus rock aggregate and steel wire reinforcement was recommended as the best system for repairing bomb-damaged craters.

b. Monsanto Research Corporation Study[A1] (May 1965 to November 1965)

(1) Introduction. This study was to evaluate the Raven Industries programs and to formulate and conduct an independent developmental effort toward the same goal. This developmental effort was to: investigate promising methods of soil solidification for subfill purposes and, additionally, consider methods of surfacing; consider economic and logistic requirements of different methods and materials; and consider and recommend equipment to be used for the repair work. Fifteen approaches to the rapid repair of bomb-damaged runways were evaluated.

(2) Materials evaluated and results.

(a) Graded density urethane foam. In this approach, the on-site fill would be used for the first lift of the crater, the top 3 feet would be filled using a graded density urethane foam. This could be 1 lb/cu ft foam for 1 1/2 ft, 4 lb/cu ft foam for 1 ft, and 10 lb/cu ft foam for the top 1/2 ft. The surface would be leveled and a urethane topcoat sprayed on to prevent erosion or abrasion. These density foams would give compressive strengths of about 10, 80, and 400 psi, respectively. A laboratory trial gave 440 psi at the yield point. Formulations were developed to give in-place densities of 2, 5, and 10 lb/cu ft. Using this technique the top 3 ft of a 70 ft crater would require between 2000 and 4000 gallons of material. A field trial path could be walked on in 10 minutes.

(b) Sulfur as a binder. Sulfur is cheap, is easily melted (246°F), can be pumped from place to place in the molten condition, and develops a high degree of strength as soon as it crystallizes from the melt. Sulfur, heated to 437°F, poured on the top surface of cold

pea-gravel (1/8 to 1/4 in. size), in a 400 ml beaker, only penetrated about 1 in. before crystallizing. Heated to 266°F in an oven, the sulfur remelted and percolated through the pea-gravel, essentially filling the voids. Two 1 in. cubes cut by a diamond saw gave a density of 147 lb/cu ft and compressive strengths of 1450 and 2100 psi. Formidable engineering problems connected with melting, storing, and handling molten sulfur and possibly aggregate heating would have to be solved before the use of elemental sulfur would be feasible (Author's enclosure: personnel at Wright-Paterson AFB report that a test strip caught fire and posed serious problems in extinguishment, not to mention air pollution).

(c) Cyanaloc 62 chemical grout. Cyanaloc 62 (American Cyanamid Company) is a resinous grouting material which adds strength and water impermeability to soft soils such as sands and gravels. Polymerization, or gelation, is accomplished by using sodium bisulfate as a catalyst. At 1:1 ratio of Cyanaloc to water and at several catalyst concentrations, no gellation took place within 24 hours. With 3:1, Cyanaloc 62 to water, gellation time was a function of the catalyst concentration - ranging from 10 to 20 minutes for 0.4 percent sodium bisulfate to less than 3 minutes for 1.6 percent. The 3:1 mixture was mixed with several proportions of sand using catalyst concentrations from 0.4 percent to 10 percent. Although the samples gelled, none became hard after standing overnight. Even undiluted Cyanaloc 62 with 2 percent catalyst would not harden when mixed with four times its weight of sand.

(d) "Liquid Plug" method of repair. Water or some other incompressible liquid would be used to fill most of the crater volume to perhaps 6 in. from the surface. A strong, impervious bag of proper dimension could be used to contain the liquid. A mesh material, similar to

the mats used on landing barges, could be pulled across the top of the bag and anchored in place. The final surface would rest on this mat and should possess the maximum in load bearing qualities. The load transmitted through the surface layer would be transmitted through the liquid equally throughout the crater. The only evaluation of this technique was to fill a 2 ft x 2 ft x 2 ft hole with water in a polyethylene bag and to apply a 1/2 in. surface layer of quick-set cement. This would support a person's weight, a feat not possible with unsupported cement.

(e) Thermosetting resins. Four phenol and ureaformaldehyde type, acid-catalyzed, foundry resins were evaluated as binders for runway fill: UF-111 and C22-30 (Monsanto Company), and Self-Set #1 and Self Set #15 (Aristo International). When used alone, the UF-111 resin and the Self-Set resins could be catalyzed for sufficiently rapid reactions to be useful for this application. However, when used as a binder for sand, the reactions could not be controlled to the point of usefulness.

(f) Prepreg fiber-reinforced sheets and films. Other types of surfacing systems are thermosetting sheet materials such as glass, nylon or canvas, impregnated with polyester epoxy, or other "B" stage resins, which could be reacted by heat after being placed in position. These were not investigated, however, in view of other, more promising approaches.

(g) Joosten Process. This process involves the consolidation and stabilization of permeable soils using sodium silicate (water glass) solutions and various precipitants. The reactants cause the precipitation in situ of gelatinous silicic acid, or insoluble silicate gels, which cement the soil particles into a load-bearing, water-impermeable mass. The Joosten Process as usually

applied, consists of injecting into the soil a solution of sodium silicate (most references refer to a Na_2O to SiO_2 ratio of 1:3.3) followed by a second injection of calcium chloride. A gelatinous precipitate of calcium silicate is formed. Soil to chemical ratios of greater than 9:1 are recommended. Quite a few experiments were made treating sand with various combinations of sodium silicate and calcium chloride. Some of the sample appeared to be water impermeable but none were load bearing. They had the consistency of wet, well-tamped sand. The replacement of part of the calcium chloride coated sand by sand and portland cement resulted in materials that hardened in a reasonable length of time and had compressive strengths between 90 and 220 psi, measured on 1 in. cube samples. Distribution of carbon dioxide gas through sand wet with a sodium silicate solution was very poor, but, where the gas could penetrate, the sand was rapidly bound into a hard, load-bearing mass.

(h) Asphalts. Asphalts are generally characterized by low compressive strength and by extreme temperature dependency. Recent improvements in asphalts made them worthy of some consideration, but they were not further considered in this study.

(i) Calcium acrylate. Calcium acrylate is a monomeric, water-soluble polyelectrolyte which will polymerize in the presence of a catalyst system to a water-insoluble polymer. Polymerization in aqueous solutions occurs at temperatures as low as 32°F. Set times of 10 to 20 minutes were obtained with several soil types when 6 percent catalyst concentration (equal parts of ammonium persulfate and thiosulfate) was used. Calcium acrylate successfully solidified all types of soils except pure kaolinite clay. The compressive strengths of several

of the solidified soil systems ranged from 1000 to 3000 psi, measured after one week of cure. Although the calcium acrylate system appears promising, it appears to be extremely sensitive to the amount of catalyst and water. Further, it is available only in laboratory or small pilot-plant quantities at a price ranging from $3.00 to $7.00/lb.

(j) Calcium ligno-sulfonate system. The lignin-sulfate waste obtained from the manufacture of paper can be oxidized with bichromate to form an insoluble gel. This type of system has shown considerable promise as a soil stabilization agent. This system is economically attractive since disposal of lignin-sulfite liquor is a current industrial problem. This lead was not investigated further in this study.

(k) Fuel oil-molasses systems. The primary potential advantage of this system is the availability and inexpensiveness of the materials. A polymerized asphaltic fuel oil - powdered molasses composition called Plasmofelt has been developed for the Marine Corps and shows considerable promise in stabilizing beach sands. Heat is required for application and reaction of this system, and it has a cure time of about 2 hours. Other similar materials may have even more desirable qualities (room temperature and accelerated cures), but other leads appeared more promising.

(l) Quick-set cements. (As mentioned before, these will be treated in Part C of this section.) Three quick-set cements were investigated: (1) PorRoc (Hallemite Corporation, Cleveland, Ohio); (2) MiraMent (Seddon Company, Springfield, Ohio); and (3) Speed-Crete (CMP, Inc., Crystal Lake, Illinois). MiraMent was the most promising of the cements.

(m) Epoxy resins as aggregate or soil binders. It is believed that epoxy resins offer advantages not realized with other polymers,

such as bonding to cement and asphalts. Epon 828 (Shell Chemical), the reaction product of bisphenol A and epichlorohydrin, as well as Epon 812, 815, and 820 were investigated. About 25 percent of Epon 828, on a soil basis, was required to give a workable mixture. Cure times with a large amount of filler were excessive when room temperature curing agents tetraethylenepentamine (TEPA) or triethylenetetramine (TETA) were used alone. Of ten accelerators evaluated in Epon 828 containing about 12 percent TEPA, three sufficiently catalyzed the reaction to give acceptable cure times - acetic acid, phenol, and borontrifluoride monoethylamine (BF_3•MEA) complex. Phenol was least effective of the three and presents a hazardous handling problem. Acetic acid appeared to be most effective at about 4 weight percent; BF_3•MEA, at between 2 to 3. These Epon mixtures were used as bonding agents for sand and earth at epoxy contents ranging from 8 to 40 percent. Cure times were in the order of 2 hours. Compressive strengths ranged from 1500 psi for about 11 percent epoxy to over 10,000 psi for 40 percent epoxy. A 1:1 combination of screened sand and pea-gravel (1/8 in. to 1/4 in.) with only 5 percent of epoxy as a binder gave a compressive strength of 1600 psi; 10 percent epoxy, about 2400 psi. BF_3•MEA does not catalyze with sufficient rapidity at low temperatures and Epon 828 becomes too viscous to afford easy mixing with sand. An examination of some other catalysts showed dichloroacetic acid (DCA) to be best and its action was a direct function of the weight percent used. A 1:1 mixture of Epon 828 and Epon 812 gave the desired fluidity. At 35°F, 15 percent of this epoxy blend in a brick sand filler had cure times decreasing from 2 hours at 4 percent DCA to 18 minutes at 12 percent DCA. About 11 percent of the TETA curing agent was used in these studies.

(n) Epoxy with expanded fillers. On the basis of limited experimentation, the use of expanded fillers (foamed polystyrene beads and expanded vermiculite) appeared to be a promising approach to filling bomb craters. Some advantages in using these materials would be: (1) low density material which could be blown into the crater at a high rate by a pneumatic system; (2) good load bearing properties with a low density material; (3) reduction in weight of material handled; and (4) low cost. The principal disadvantage would be the shipment of large quantities of high-volume, low-weight material. Possible solutions to this problem are to expand the materials on site, either by the exotherm from the curing resin or by a separate system. Studies with vermiculite indicated that temperatures from 500°F to over 800°F, depending on grade, were necessary. These temperatures are too high for any exotherm and probably impractical for an on-site auxiliary expansion system. An exotherm sufficient to expand the polystyrene beads could be obtained from the epoxy binder; however, when expansion occurred, voids in the center of the mass also occurred. Conditions could undoubtedly be developed when some expansion would take place without forming voids, but control over this type of system would be extremely sensitive and, therefore, not suitable.

Tests of epoxy - expanded vermiculite systems showed that a minimum of 2 parts by weight epoxy to 1 part by weight vermiculite was necessary to get compressive strengths in the 300 to 500 psi range. This mixture is only 20 percent epoxy by volume, however. A 3:1 weight composite gave a strength of 1050 psi.

(o) Resin cement systems

((1)) Quick-set cement-calcium acrylate. Adding about 5 weight percent of calcium acrylate to a 3:1 brick sand-MiraMent cement mixture changed a gel time of

about 1 hour and a set time of 12 hours to 10 minutes and 20 minutes respectively. The addition also produced an abrasion resistant material; whereas, without calcium acrylate, the set material was easily abraded.

((2)) Epoxy-cement combinations. Quick-set cements will not bond to existing cement and asphalt surfaces and have low flexural strengths. Epoxies will bond to these surfaces and have relatively high flexural strengths. It thus seems appropriate to try combinations to get the desirable properties of both. In initial mixtures, the gel times were satisfactory but set times (time to the load bearing stage) were excessive. A rather extensive investigation showed that Epon 812 (a mixture of branched di- and tri- epoxides) was the only member of the Epon series which cured well in combination with cements. The other Epons are of the epichlorohydrin-bisphenol A type and are not as water soluble. In one series of tests, maximum compressive strength of about 2500 psi was obtained at 4 percent to 8 percent of Epon 812 based on the MiraMent cement; strength was about 800 psi at 0 percent Epon 812 and about 1000 psi at 15 percent Epon 812. One formulation, which cured under water at room temperature in 10 to 20 minutes, took about an hour to cure under water at 35°F. A formulation recommended for maximum strength characteristics:

100	parts MiraMent
10	parts Epon 812
10	parts water
1.6	parts TETA
0.2	parts DCA

This mixture was easily workable, hardened in 15 to 20 minutes to a load bearing mass, and cost about $0.12/lb.

(3) Field testing. Three of the preceding fifteen systems were selected for small scale field demonstrations at Wright-Paterson AFB.

(a) Epoxy-sand system. A mixture of Epon 828 and Epon 812 was used. In the first trial at a temperature of 40°F, these epoxies mixed with brick sand and pea-gravel never set to a firm mass. Subsequent tests showed that too much water was present - the sand contained over 25 percent. In a second trial, using dried aggregate at a temperature of 30°F, cure took place in 30 to 40 minutes. Sixteen passes of the rolling wheel at a load of 25,900 lbs had no effect. Using 100 percent of the more hydrophilic, but also more costly, Epon 812 should reduce the water sensitivity of this system.

(b) Cement-epoxy system. The Epon 812 and MiraMent cement were premixed and stored 4 days in fiber-packs before use. This resulted in some caking. Some cakes did not break up in the mortar mixer and chunks from 1 in. to 4 in. in diameter were placed in the hole. The repair, however, was quite effective - the material hardening in about 30 minutes at a temperature of 35°F. Eight passes were made at a load of 11,000 lbs and 2 passes at a load of 19,600 lbs before the material cracked away from one side. Two more passes at 19,600 lbs had no effect, but the testing was stopped.

(c) Cement sand-system. Varying amounts of pea-gravel were used to minimize the amount of MiraMent cement used. At a temperature of 42°F, the material set in 1 hour after pouring and testing started in 1 1/2 hours. This was the easiest system to field mix and pour. Tests consisted of 8 passes at 11,000 lbs, 16 passes at 19,600 lbs, 16 passes at 23,800 lbs, and 16 passes at 25,900 lbs. Some surface cracks occurred after 8 passes at 19,600 lbs, but did not penetrate deeper with subsequent tests.

c. The Western Company Study[A2] (31 May 1966 to 31 December 1966)

(1) Introduction. In this study, 170 polyester and vinylester resin formulations, 61 epoxy resin formulations, and 250 fast-setting cement formulations were investigated. A laboratory program determined the relative degree to which various resin formulations possessed certain desired characteristics such as low viscosity, short cure time, reasonably low maximum exotherm, and adequate compressive and flexural strength. Since rapid-repair situations require resin runways to be loaded before they have time to cool appreciably following the cure exotherm, strength tests on relatively thick specimens were performed while they were still hot - 30 minutes after cure was initiated by the addition of catalysts. Another aspect of the laboratory program was to develop a resin formulation that performed satisfactorily at temperatures as low as -5°F.

(2) Materials evaluated and results

(a) Polyester and vinylester resins. Two resins were selected for field testing from the 170 received for laboratory evaluation: a polyester - Laminac 4128 (American Cyanamid) and a vinylester - Derakane 114 (The Dow Chemical Company). Another polyester, Plaskon K5 5541 (Allied Chemical), exhibited excellent properties but was not available in quantities required for full testing. Derakane 114 was selected because of its inherent low viscosity, even with 60 percent of added fillers. Formulations selected for field testing were:

Resin	Catalyst	Coupling Agent	Filler
Laminac 4128	Lupersol 224	Methacryloxy-propyltri-methoxy-silane	15% 10-micron silica + 15% glass fibers
Derakane 114	Lupersol 224	None	60% 10-micron silica

Catalyst concentrations necessary to give 5 to 10 minute gel times and 15 to 20 minute cure times were established for each of these formulations for the range of ambient temperatures expected during the field test. In developing +30°F and -5°F formulations, several procedural modifications were required: (1) all components of a formulation were allowed to come to the test temperature prior to viscosity determinations or cure initiation; (2) cardboard molds were used for these tests (standard metal molds extracted heat from the reacting sample and prevented cure); (3) samples prepared for strength testing were removed from the cold environment just prior to testing. There are two principal problems in utilizing resins below the freezing point of water, the great increase in viscosity and the reduced reactivity. To keep polyester resins pumpable at low temperatures, active diluents were added, e.g., additional styrene, divinylbenzene, methylacrylate and vinyltoluene. The most direct means to increase the reaction rate was to use two promoters, such as cobalt naphthanate and dimethyl-aniline, in high concentrations. The most effective cold temperature formulation was:

Resin:	Laminac 4128	34.3%
Active diluent:	Methylacrylate	7.0%
Active diluent:	Styrene	7.0%
Inert filler:	Glass fiber (1/32" long)	25.0%
Inert filler:	10-Micron silica flour	25.0%
Catalyst:	Lupersol 224 (mixed ketone peroxide)	1.0%
Promoter:	Cobalt Naphthanate (6%)	0.7%

(All percentages are by weight)

Viscosity of uncured resin formulation: 56 poise
Flexural strength of cured resin formulation: 3000 psi

(b) Epoxy resins. An epoxy resin was not chosen when compared to polyester and vinylester resins, because: (1) epoxy resins represent a more complex system since for rapid cure both a cross-linking agent and a catalyst, instead of just a catalyst, must be added and blended; (2) pot-life was affected by the mass of material (gel life of polyester and vinylester resins was independent of mass); (3) when cured rapidly, the cure exotherm was generally more severe (a larger quantity of filler has to be added to an already viscous fluid); (4) epoxy resins were more expensive. Some comparative properties, including cost, of these three main systems are given in Table II (their Table III).

(c) Fast-setting cements (Fast-Fix). The Western Company Study of "Fast-Setting Inorganic Cements" is included in Section III.C.2. under "Calcium Sulfates."

(3) Field testing. Field testing procedures were conducted over soils of varying strengths. It was established that an organic material thickness of about 5 in. was needed over a 4 CBR soil base to carry 16 passes of the 29,000 lb load. Laminac 4128 was the most satisfactory. Derakane 114 had most of the characteristics of

TABLE II

COMPARISON OF PROPERTIES OF THERMOSETTING RESINS

Property	Poly-Ester	Vinyl-Ester	Epoxy
Uncured			
Viscosity	3 to 25 poise	0.5 to 1.5 poise	1 to 100 poise
Specific gravity	1.13	1.04 to 1.09	1.1 to 1.3
Cost per pound	$0.29	$0.33	$0.50
Reactivity	Inert without catalyst	Inert without catalyst	Amine and resin will react without catalyst
Curing			
Gel time	3 minutes	5 minutes	15 minutes
Cure time	6 minutes	10 minutes	30 minutes
Peak exotherm	350 to 420°F	450°F	300 to 400°F
Cured			
Flexural strength	15,000 to 22,000 psi at 77°F	18,000 psi at 77°F	18,000 psi at 77°F
Tensile strength	5,000 to 10,000 psi at 77°F	10,500 psi at 77°F	8,000 psi at 77°F
Change in volume	Shrinks 6 to 8%	Shrinks slightly	Shrinks or expands

the polyester, but was difficult to cure at temperatures below 32°F. The best field solution, needing less resin, was to percolate the catalyzed Laminac 4128 through 3/4 in. gravel. Thicknesses of 4 in. or more over a 4 CBR base carried the required load.

(4). High speed resin mixing equipment. A design of mixing and in-placing equipment was carried along concurrently with the material development. To fill the entire 3,900 cu ft crater cavity in 15 minutes, a mixing and pumping rate of about 2,000 gallons per minute (gpm) is needed. With aggregate of a uniform size used to fill about 50 percent of the cavity, the rate could be reduced to about 1,000 gpm. For scale-model tests using 10 ft x 10 ft test panels, a flow rate of 35 gpm is indicated. In developing the 35 gpm scale-model, conventional resin mixing equipment designs were rejected because of pump rate limitations for a full-scale model. A system was designed in which basic resins, fillers, and additives (other than the catalyst) were preblended in a tank. These materials were then pumped with a screw-type pump through an in-line mixer. The catalyst was metered and injected into the mix just upstream from this mixer.

d. Air Proving Ground Center Study(A13) (Before February 1965)

(1) Introduction. To determine the base course and wearing surface needed in repairing a runway crater, four basic construction techniques and/or material types were investigated: (a) conventional - macadam base with an asphaltic surface treatment to stabilize the loose surface material; (b) prefabricated rigid sections - a prefabricated

bridging material to act as both base course and wearing surface; (c) conventional base materials with a grout surface; and (d) compacted graded aggregate as base course and wearing surface.

(2) Materials withdrawn from consideration.

(a) Polyester resins

(b) Polyurethane foam

(c) Thermoplastics

(d) Epoxies

(e) Hot mix asphalt

(f) Prefabricated, prestressed concrete sections

(g) Most rapid setting grouts

These materials were investigated but withdrawn from consideration because of obvious characteristics that would preclude their meeting certain portions of the set repair criteria. Materials extremely sensitive to temperature or humidity conditions and/or to time criteria - either in placing or in taking a set - were eliminated. Other materials were rejected because of the sophisticated skills and equipment necessary for use.

(3) Materials evaluated and results.

(a) Compacted aggregate with asphaltic surface treatment.

((1)) RC-4. The surface area was shot with this rapid curing, cut back asphalt at the rate of 0.2 gal/yd and lightly sanded. There was slight tackiness immediately after placing, but not enough to cause a problem. Four passes with the rolling wheel (29,000 lb on a tire inflated to 256 psi pressure, testing started 15 minutes after placing) caused a 1 in. rut. It was concluded

that, under suitable temperature and weather conditions, RC-4 would be an accepted surface seal coat.

((2)) Amicrete (Southern Amestite of Birmingham). This is a patented, dense graded, asphaltic cold mix. The maximum size of the aggregate in this mix was 3/8 in. The compacted thickness of this surface layer was 1/2 to 3/4 in. This surface had little if any tack immediately after placing. Four passes with the loaded. rolling wheel caused a 2 to 4 in. rut. Amicrete was considered unacceptable because of lack of stability.

((3)) RS-3K. The surface area was shot with this rapid curing, cationic asphalt emulsion and sanded. This material remained tacky for 2 to 3 hours and is considered unsatisfactory because of this long curing time.

(b) Surface with prefabricated rigid sections.

((1)) Prestressed concrete slabs. Initial thought was given to using prestressed concrete slabs or structural units. This plan was not investigated because of the difficulty of handling such units in a rapid and efficient manner because of their weight.

((2)) Metal landing mats.

((a)) T-11. This is an extruded aluminum mat developed by the U. S. Corps of Engineers Waterways Experiment Station. Panels are made in 2 ft x 6 ft and 2 ft x 12 ft sizes. They consist of a top plate reinforced with ribs, 3 in. on centers, along the underside; have necessary joining flanges; have a total thickness of 1 5/8 in.; and weight 4 1/2 lb/sq ft. (In using all metal landing mats, the repair technique was to assemble the panels into the required size patch off, but as near as possible to the damaged area, at the same time that the crater is being filled flush to the original runway surface. The patch is then pulled over the filled crater and ramps are installed

at the entering and leaving edges of the patch to carry the wheel loads over the patch.) The T-11 panels proved questionable in use because the exposed ribs on the underside would cut into the relative soft fill, causing flexing and induced stresses.

((b)) Air-Dek (U. S. Steel Corporation). This is a steel mat having upper and lower plates of 20-gauge Cor-Ten steel with a core of egg crate-type steel. Each section is 4 ft x 4 ft with a tongue and groove edge to join adjacent sections. Overall thickness is 2 in. and the weight is 7 lb/sq ft. Air-Dek passed the loading tests.

((c)) AM-2. This is an extruded aluminum mat developed by U. S. Navy Civil Engineer Laboratory. It is similar to the T-11 mat except that it has a lower plate in addition to the upper plate, separated by the ribs. Panel sizes are the same: 2 ft x 12 ft and 2 ft x 6 ft. Overall thickness is 1 1/2 in.; weight is 6 lb/sq ft, and cost is $3.50 to $4.00/sq ft. The AM-2 mat also passed the loading tests and is the recommended one of the three tested.

(c) Conventional base materials with grout surfaces.

((1)) Hydrocal (U. S. Gypsum)

((2)) PorRok (Hallemite Mfg. Co.)

((3)) Siroc (Diamond Alkali Co.)

These will be discussed under fast-setting cements (Section III.C.)

(d) Compacted graded aggregate as base course and wearing surface. The aggregate used meets the requirements of Corps of Engineers Specification 807.07 "Guide Specifications for Graded - Crushed Limestone." The gradations are given in Table III. In the best repair, which only had a slight rut of about

3/8 in. after 24 passes of the loaded, rolling wheel, a "Vibro-Tamper" (International Vibration Company) was used. This repair was made as follows: a test hole was excavated to a depth of 3 ft and the exposed subgrade compacted with two coverages with the Vibro-Tamper; a 15 in. lift of the aggregate was placed and given 8 coverages with the tamper; 9 in. lift of aggregate placed and given 8 coverages with the tamper; 6 in. lift placed and given 10 coverages with the tamper; top 6 in. lift placed and 30 coverages with the tamper given. Extreme care was taken in handling the aggregate to avoid any segregation. (A protective cover, such as the T-15 rubberized nylon membrane, should be fastened down over this surface as protection against foreign object damage to the airplane engines from loose aggregate.) In each of two other graded aggregate fills described, the loaded cart embedded up to the axle and formed a 6 in. deep rut on the first pass. These led to the summary that a highly stable base could be made if strict control of method and material were exercised, but, with only slight reduction of effort, complete failure could result.

TABLE III

GRADATION FOR CRUSHED LIMESTONE

U. S. Standard Sieve No.	Percent Passing
1 1/2 in.	100
1 in.	60-100
1/2 in.	30-65
No. 4	20-50
No. 10	15-40
No. 40	5-25
No. 200	5-10

(4) Recommendations from exploratory testing.

(a) Backfilling crater. Use the material blown out of the crater as backfill for the subgrade unless it is too soft to permit equipment to work in the crater - then use select material, preferably coarse aggregate, to build a work platform. Level off the backfill at the prescribed distance below finish grade to accommodate the base course.

(b) Constructing base course. Construct the base or bedding course of small size aggregate or sand. Bring it up level with the surrounding pavement. It should have a CBR of not less than 3 and a depth of 12 in.

(c) AM-2 mat surface. Use AM-2 (or equivalent quality) mat to surface the damaged area. A ramp section at the leading and leaving edges is necessary, mats are preassembled off the runway while filling the crater and then pulled over...

(d) Alternate surface. Use an 18 in. thick base of close graded crushed aggregate with the surface covered with a T-15 rubberized nylon membrane or, under favorable weather conditions, with an RC-4 asphalt seal coat to prevent foreign object damage to the aircraft engine.

(e) Surfacing small craters. With limitations, PorRok concrete appears feasible as a material for surfacing small bomblet type craters where the volume required would be small and the time element is critical.

3. Specific Studies. Some studies were restricted to an in-depth evaluation of one material or class of materials. A few of these studies will be treated here with the material the topic heading.

(5) Other utilities. Material lay-down and pumping properties of materials to be utilized in the rapid repair of bomb damaged runways were investigated[A9]. The stabilization of various sand surface sites in South Vietnam was demonstrated[A7,A15]: (a) sand revetment, (b) cargo storage area, (c) test engine run-up test station, (d) helicopter landing pad, (e) maintenance hardstand area, and (f) some miscellanea, such as, patching of metal mats and revetments, overspraying of pierced steel planking, and fabrication of a short aircraft taxiway entrance area.

b. Water-extended polyester (WEP)[A6,A15]

(1) Introduction. Unsaturated polyesters have been extended with up to 70 percent water. The water-in-oil emulsions that result from mixing polyester and water are conventionally cured with peroxide-promoter combinations to give composites with good property combinations.

(2) Material composition. A large number of compositional variables were investigated and reported in this study (reference A15,b. is actually based on A6): (a) Aropol polyester resins Q6300, Q6310, 7110, 7420, and 7510M (Ashland Chemical) and Atlac 382E polyester resin (Atlas Chemical Industries); (b) styrene dilution of the polyesters to over 70 percent styrene; (c) water dilution of the total resin system to over 70 percent water; (d) catalysts - benzoyl peroxide, methyl ethyl ketone peroxide; (e) promoters - dimethyl-p-toluidine, dimethyl aniline, cobalt octoate; and (f) emulsification. The formulation eventually recommended for the final field test at Wright-Paterson AFB was composed of Aropol Q6300 diluted with 60 percent styrene, and with 60 percent water based on these resins. Catalyst and promoter levels were 1.5 percent

cobalt octoate, 0.5 percent dimethyl aniline, and 0.5 percent peroxide solution. By properly formulating the resin, the need for an emulsifier was eliminated.

(3) Properties. With a properly compacted subbase, a 4 in. depth of the "final" formulation passed the 29,000 lb moving wheel test. Table IV gives some properties of WEP compared to concrete and wood. Decreasing the water content will improve strengths; e.g. at 60 percent styrene, flexural strength is about 600 psi at 70 percent water; 1500 psi at 60 percent water; and 2400 psi at 50 percent water. Increasing the amount of styrene in the resin mix will usually increase the flexural strength, but not always. At about 70 percent styrene, the time of cure may drastically increase. At 60 percent water the composite cost is about \$0.085/lb or \$5.16/cu ft. Initial installations showed some damage due to freezing. This can be reduced by adding salt, calcium chloride, or glycol to the water or by reducing the water content from 60 percent to 50 percent.

(4) Delivery equipment. A laboratory mixer was developed to blend, mix, and emulsify 1 gpm. This was scaled up and a mixer built to deliver 10 gpm. From this a feasibility study was conducted to produce a 1000 gpm machine. This system would include: (a) resin diluted with styrene transported in 4000 gallon tank trucks; (b) resin and water pumped to mixing unit with 400 gpm and 600 gpm centrifugal pumps, respectively; (c) cobalt octoate and dimethyl aniline, used as gelation promoters, injected into resin stream with a 10 gpm metering pump; (d) water solution of peroxide catalysts injected into combined water-resin stream with 10 gpm metering pump just prior to mixing unit; (e) emulsification accomplished using a pipeline mixer with a 1000 gpm capacity; and (f) a solvent flush system using methylene chloride for reduced flammability.

TABLE IV

PHYSICAL PROPERTY COMPARISON OF WATER-EXTENDED POLYESTER COMPARED TO CONCRETE AND WOOD

Property	WEP Current	WEP* Projected	Concrete	No. 2 Pine
Compressive, psi	2,100	3,000	4,500	300 to 900
Tensile, psi	610	1,800	300	1,200
MOD Elasticity	100,000	150,000	3,625,000	1,760,000
Punch Shear, psi	555	1,000	360	--

*Estimated properties using a suitable filler.

c. Asphaltic concrete premix (Hotpatch)[A10]

(1) Introduction. In two of the general studies, asphalts are mentioned but, in one, "not considered further"[A1] and, in the other, an asphalt hot mix was "withdrawn from consideration"[A13]. In two other studies, "an asphaltic cold mix of the type used is not considered adequate for wearing course repair"[A12] and "asphalts did not lend themselves to rapid repair in the time period desired."[A5] The "Hotpatch" described in this study is recommended as a durable patch for runways and other pavement surfaces.

(2) Composition. The hot asphalt patching mixture was developed by C. E. Rhodes, an engineer in the Twelfth Naval District Public Works Office. A patent was applied for in September 1959. The mixture is a premixed, prepackaged combination of fine aggregate and emulsified asphalt (57 percent asphalt + 43 percent water). Coarse aggregate is added in the field while the mixture is heated to remove water from the emulsion. Composition of the premixed material:

Sand, fine	- 75% by weight, passes a No. 40 sieve
Limestone dust	- 25% by weight, passes a No. 200 sieve
Emulsified asphalt	- 38% by weight of sand and limestone dust
Hydrated lime	- 1% by weight of sand and limestone dust

Coarse aggregate up to 1/2 in. is added in the field.

(3) Heating and mixing. To mix and heat the material in one operation, a Littleford Model 700 heater-mixer

was purchased. This handles 7 cu ft of material at one time. It took an average of 6 minutes to drive all water from the mixture and heat to the desired temperature of 300-350°F. The mixer contains a separate aggregate compartment in which the coarse aggregate for the next batch can be preheated by direct flame from the burners while a complete batch is heating and mixing in the mixing drum.

(4) Properties. The resulting asphaltic concrete is high-quality, as indicated by the high values of Marshall Stability obtained on specimens made in the laboratory and molded in the field. Patched areas were in good shape after over a year's service. The cost of the experimental quantities purchased from two commercial sources was high, being about $2.50 per 75 lbs, not including the cost of the package. The cost of a 3 in. thick patch would be $0.75/sq ft + coarse aggregate cost + container cost + labor cost. This is nearly double conventional asphaltic concrete costs. The premix material should be packaged in waterproof containers.

C. FAST-SETTING INORGANIC CEMENTS

1. Introduction. Ordinary portland cement (Type I, see ASTM C150), after specified formulation with aggregate and water, takes nearly 3 days to reach a compressive strength of 1200 psi. Type III portland cement ("for use where high early strength is required"), due to slight compositional changes, reaches a compressive strength of 1700 psi in 1 day after hydration. Neither of these reaches the desired compressive strength of 1000 psi in 30 minutes, but Type III cement compared to Type I shows that slight compositional changes can greatly accelerate the rate of cure. Certain materials, such as anhydrous and semihydrate calcium

sulfate (plaster-of-Paris) when mixed with water are fast setting. Certain organic and inorganic materials serve to accelerate the set of concrete. The finer the powder one grinds the cement clinker into, the faster the subsequent hydration and the faster the set. Increasing the cure temperature will accelerate the set of most concretes.

2. Calcium Sulfates.

a. Commercial gypsum cements. The U. S. Gypsum Company manufactures a large number of gypsum cements tailored for various industrial uses. All are essentially alpha gypsum (gypsum semihydrate, plaster-of-Paris, $CaSO_4 \cdot 1/2\ H_2O$), differing in granular shape and density and in additives. Table V gives mix proportions, setting times, and compressive strengths for some of these cements.[B11] Note that these cements, typically, expand on setting. Further data on four of these cements which are used in formulating "Fast-Fix" cements follow.

(1) Hydro-Stone.[A2] Heat and pressure during processing into the semihydrate gives a dense, needle-like granular particle. All gypsum semihydrates need about 19 percent water, based on weight, to fully hydrate back to the dihydrate ($CaSO_4 \cdot 2H_2O$). The dense Hydrostone crystal only needs 13 percent additional water (total of 32 percent) to produce a pumpable slurry. As received from the manufacturer, Hydrostone is about 90 percent $CaSO_4 \cdot 1/2\ H_2O$ and 10 percent lubricators or fluidizers. Set times varied from 12 to 40 minutes. Early compressive strengths, about 30 minutes after pouring, were 3500 to 4000 psi. A slight contamination of the slurry with soil, dissolved salts, portland cement, etc., affects the set time. As received, price was about \$3.30/cwt.

TABLE V

PHYSICAL DATA ON GYPSUM CEMENTS

	Normal Consistency: Parts water to 100 parts Gypsum Cement by Weight to Make a Pourable Slurry	Setting Range in Minutes (Vicat)	Typical Setting Expansion Inches per Inch	Average Compressive Strength Lbs per Sq Inch Dry*	Reaction
Ultracal "30"	35 - 38	20 - 30	.0003	7300	Alkaline
Ultracal "60"	36 - 39	75 - 90	.0002	7300	Alkaline
Hydrocal A-11	40 - 42	16 - 21	.0005	4500	Alkaline
Hydrocal B-11	46 - 49	24 - 33	.0005	3800	Alkaline
Hydrocal B-11 (Slow Set)	46 - 49	45 - 55	.0004	3800	Alkaline
Hydro-Stone	28 - 32	17 - 23	.002	11000	Alkaline
Industrial White Hydrocal	40 - 43	20 - 30	.003	5500	Neutral
Pattern Shop Hydrocal	54 - 56	17 - 23	.0015	3200	Neutral
Industrial Molding	64 - 66	27 - 37	.0018	2000	Neutral

*Figure for wet strength is about half dry strength.

Further information on the high strength of Hydro-Stone water mixes, especially when dry, is given by Bendinelli:[B8a]

Hydro-Stone lbs	Water lbs	Cure	Compressive Strength psi
100	30	30 hrs, ambient	3990
100	25	24 hrs @ 100°F	6780
100	35	24 hrs @ 100°F	4090

(2) IP Cement.[A2] This cement particle is sponge-like and mixes well with water, but needs more water (a total of 64 percent) to make a smooth, pumpable slurry. Due to the increased water, 30 to 60 minute compressive strengths were 1500 to 2000 psi. The low price of $1.20/cwt makes this product attractive.

(3) Hydrocal White.[A2] Hydrocal White has the same needle-like crystals as Hydro-Stone and needs about the same total amount of water (35 percent) to produce a good slurry. Compressive strengths at 30 minutes were about 3250 psi. It is priced at $2.20/cwt.

(4) Ultracal "30".[A2] Ultracal "30" has the same needle-like crystals as Hydro-Stone and Hydrocal White and produced smooth, pumpable slurries. Set time, however, was too long - over 25 minutes. The earliest reported strengths were taken 50 minutes after pour, and were generally low. No field testing was done on this material.

b. Fast-Fix Cements (The Western Co.).

(1) Introduction. Setser el al[A2] evaluated some 250 fast-setting cement formulations in an effort to find materials that could meet the specifications for "rapid repair of bomb-damaged runways." The four U. S. Gypsum

cements, just discussed, proved most adaptable to rapid repair techniques. Materials tested that did not meet the requirements were portland cement, Lumnite cement, PorRoc, MiraMent, Speed Crete, Florok, Sika accelerators, Darex, Dehydratine 80, and sodium silicate. The gypsum cements were not suitable alone, but required from 5 to 20 percent Type I portland cement to reduce and stabilize set times; from 0.5 to 1.5 percent of Western's TF-4 dispersant to reduce the mix water required and thus give higher strengths; and usually required some of Western's WR-1 or WR-6 cement set-time retarder.

(2) Formulations.[A2]

(a) Fast-Fix 1. The recommended cement composition was 95 percent Hydro-Stone cement + 5 percent portland cement + 0.5 percent TF-4 based on the total cement. Optimum water content was 32 to 35 percent based on cement. Due to the high early strength and the dense, abrasion resistant surface of the cast mortar, Hydro-Stone was considered superior to the other U. S. Gypsum products tested. The set time, however, was erratic, ranging from 8 minutes to an hour. It was found that up to 5 percent of Type I portland cement had no detrimental effect on final strength and stabilized the set time at 8 to 12 minutes. Using the TF-4 dispersant, the mix water could be reduced to a level which gave the high early flexural and compressive strengths while maintaining a low viscosity slurry which was easily pumped. At water levels less than 35 percent, 1 percent TF-4 appeared to be needed; at water levels of 40 percent or more, little or no benefit from TF-4 was realized. Since, for good percolation through crushed stone, a 40 percent water slurry was deemed necessary, TF-4 content was set at the 0.5 percent level. It was found that

Fast-Fix 1 could be mixed with as little as 30 lb of water per 100 lb of cement[A3]. This material hard set in 12 to 15 minutes, giving a 30-minute compressive strength of 4000 psi and flexural strength of 700 psi.

(b) Fast-Fix 2. Fast-Fix 2 is composed of IP Cement and portland cement. Composition ranges are given as: 80-95 percent IP Cement, 20-5 percent portland cement, 0.5-1.5 percent TF-4 based on the total cement, and 50-70 percent water based on cement. In a series of tests, holding the water constant at 60 percent, using 1 percent of TF-4, portland cement was varied from 10 to 40 percent. The best 20 to 60 minute strengths were obtained at 20 percent portland cement - 1800 psi compressive strength and 578 psi flexural strength. Using the 80 percent IP Cement:20 percent portland cement blend mixed with 55 percent water, and using the TF-4 concentrations of 0.5, 1.0, and 1.5 percent gave 1 minute viscosities of 310, 160, and 60 centipoise, respectively. Fast-Fix 2 sets very quickly - within 3 to 5 minutes after pouring. To increase the set time, a small amount of WR-1 set-time retarder (The Western Co.) can be added. WR-1, because it prevents early gelling of the cement slurry, makes possible slurries with lower water content. Compositions with 20 percent portland cement + 1 percent TF-4: (1) with 0.2 percent WR-1 formed a slurry with 35 percent water which set in 12 minutes and gave a 30-minute compressive strength of 2220 psi; (2) with 0.1 percent WR-1 formed a slurry with 40 percent water which set in 15 minutes and gave a 30-minute compressive strength of 2200 psi; (3) with 40 percent water and 0.3 percent WR-1, set time was 38 minutes, 1-hour compressive strength was 2150 psi.

(c) Fast-Fix 3, Fast-Fix C-1. Fast-Fix 3 originally formulated to have 95 percent Hydrocal White cement + 5 percent portland cement + 0.5 percent TF-4. For a mix with 40 percent water, set time was about 5 minutes

with a 30-minute compressive strength of 3250 and flexural strength of 756 psi. In another report[(A3)], the same formulation is said to hard set in 8 to 12 minutes and to have a compressive strength of 3000 psi and a flexural strength of 600 psi in 30 minutes. In later reports[(B3,B7,B10)], Fast-Fix formulations containing Hydrocal White are known as Fast-Fix C1. Fast-Fix C-1 contains 20 percent portland cement, while Fast-Fix 1 contains 5 percent, so Fast-Fix C-1 should be more resistant to erosion by water[(B3)].

(d) Fast-Fix 4. Fast-Fix 4 contains Ultracal "30" cement. Ultracal 30 is slower than the previous three gypsum cements in gaining initial set and strength. Set times were over 25 minutes and the earliest reported strengths are at 50 minutes. Set times for a 45 percent water slurry varied from about 42 minutes for compositions with 0 percent portland cement to a minimum of about 29 minutes for compositions with about 31 percent portland cement. With adequate cure times, strengths were greater than Fast-Fix 2 formulations. Potassium sulfate could be used to accelerate cures, but, when enough was used to substantially reduce the set time, difficulty was had with mixing.

(3) Low Temperature Mixing.[(A2)] If the resultant Fast-Fix 1 slurry temperature is 40°F, or greater, normal hydration and set occur. Using 35 percent of mix water, if the cement is at -5°F, the temperature of the mix water would have to be 74°F to give this 40°F slurry temperature. A small amount of a weak acid, such as dilute hydrochloric, by reaction with a part of the portland cement, is very effective in raising the slurry temperature.

Two commercial accelerators, Sika No. 2 and Sika No. 4-A, which remain liquid at -5°F, were also used to achieve set at low temperatures. When mixed with Fast-Fix 1 at -5°F, the slurry set in less than 2 minutes,

giving 30-minute compressive strengths between 600 and 800 psi. These materials are too expensive and too fast for field use. A sodium silicate solution performed equally as well as the Sikas at a much lower cost, but excessively fast slurry setting occurred here, also.

(4) Fillers and reinforcing materials.[A2] Used in Fast-Fix 1 at 35 percent water content, from 10 to 50 percent of fine sand (<0.59 mm, passing a No. 30 mesh) had very little effect on 30-minute compressive and flexural strengths. They were greater than 3000 psi and about 500 psi, respectively. In using coarse sand (0.71 mm to 2.00 mm), most large grains tended to settle out.

Chopped fiber glass (1/8 in. long fibers) was dry blended into Fast-Fix 1. At fiber glass concentrations up to 2 percent, little effect was observed on mixing at a given water concentration; for concentrations over 2 percent, longer mixing times were needed and it was difficult to achieve a homogeneous mix. Increased compressive and flexural strengths were obtained, but due to cost and the increased difficulty in mixing, it was not believed that the use of fibers could be justified.

Cloth, roving, and matting were of little use as reinforcing materials as the cement slurry did not completely penetrate them. Loose fiber glass in 6-in. lengths appeared the most promising. When placed in flexural molds and a 35 percent water-cement slurry poured over them, a flexural strength of 1060 psi was obtained at 1 hour after the pour.

(5) Some miscellaneous properties and uses.

(a) Thin slab tests.[A3] Thin slabs of from 0.125 to 2.75 in. in thickness were poured using Fast-Fix 1,

40 percent water slurries over a wide selection of surface types (sand, clay, gravel and black clay with either a heavy mat of dead grass or a heavy mat of growing grass). Soils varied from a CBR of 1 to 10. Very thin sheets prevented sand movement when there is no traffic; sheets from 0.125 to 0.25 in. thick supported foot traffic over loose sand or heavy muddy soil; slabs from 1.25 to 2.0 in. thick supported light vehicular traffic.

(b) Soil consolidation.[A3] Six graded sand sizes and a "mixed gravel" blend of these were used to fill 4 in. pipes. Fast-Fix 1 slurries were poured in the top and allowed to percolate through, being careful to prevent flow at the pipe wall. Depths penetrated are given in Table VI for the various sand gradations and for various mix water percentages. For the 45 percent mix water slurry, significant penetration took place for the sands greater than 1.10 mm and for the mixed gravel. For these consolidated sands, the 40-minute compressive strengths averaged about 1200 psi compared to 2000 psi for the neat mortar.

(c) Freeze-thaw resistance.[A3] Forty-three test blocks were molded, with a thermometer molded in one. Blocks were cycled until the thermometer read 0°F, then warmed until the thermometer read 50°F for 14 times. Three blocks were tested in compression after each cycle. There was no significant change in strength. The average for all tests was 3500 psi. Fast Fix 1 + 35 percent water was used. (No statements are made relative to the moisture content of the specimens.)

(d) Large cylinder strength.[A3] Fast-Fix 1 + 40 percent mix water was cast into cylinders 6 in. in diameter and 12 in. long, and tested in unsupported compression. Compressive strength at 30 minutes was 2930 psi; at 7 days, 3160 psi; and at 14 days, 2940 psi.

TABLE VI

DEPTH OF PENETRATION OF FAST-FIX SLURRIES INTO SAND

			Depth Penetrated (in) for Industrial Sand Size						
H_2O (%)	Slurry Weight	Viscosity (cp)	- .71 (mm)	-1.19 + .71 (mm)	-1.68 +1.19 (mm)	-4 +1.68 (mm)	-6 +4 (mm)	-12 +6 (mm)	Mixed Gravel
32	16.1	350	.031	.125	.187	.25	.50	3	1.0
35	15.8	230	.031	.25	.31	.50	8.0	12	1.0
40	15.2	65	.031	.50	1.2	8.0	+12.0	+12	2.0
45	14.9	47	.031	2.0	8.0	12.0	+12.0	+12	+12.0
50	14.5	32	.031	4.0	+12.0	+12.0	+12.0	+12	+12.0

(e) Effect of water.[B3] Prisms cast from Fast-Fix C-1 concrete were half immersed in water. These showed very little evidence of water solubility, so one was exposed flat-wise perpendicular to a stream of water with a diameter of about 1/4 in., falling 7 in. from the faucet. After 28 days, a depression about 3/4 in. in diameter and 1/8 in. deep was eroded. A similar prism of Fast-Fix 1 concrete showed a much larger cavity after only 3 days.

(6) Runway patch tests.

(a) Bomb-damaged runways.[A2,A3] Fast-Fix 1 and Fast-Fix 2 cements were used to demonstrate the utility of the Fast-Fix cements for the "rapid repair of bomb-damaged runways." As previously discussed, Fast-Fix 2 gypsum particles are spongy while Fast-Fix 1 gypsum particles are hard needles; Fast-Fix 2 needs more water for equal flowability; water reduces strength. Thus, for equal patch thickness, Fast-Fix 2 should be weaker than Fast-Fix 1. This was shown on small scale (20 ft diameter) crater repairs at Elgin AFB. A 7 in. cap of neat Fast-Fix 2, just below the predicted needed thickness, failed as predicted; a 6 1/2 in. cap of neat Fast-Fix 1, on a 39 ft diameter crater, carried the 39,000 lb single wheel load for 16 passes and the whole load, 78,000 lb on two wheels, parked for 3 days in the center of the patch. The recommended repair is to percolate the Fast-Fix slurries through pea-gravel or crushed rock (the gravel fills about 50 percent of the space) allowing a final top thickness of 1 or 2 in. of neat slurry. Using this technique, an 8 in. patch of Fast-Fix showed one small crack on the twelfth pass. All repairs at a total thickness of 12 in. (11 in. of gravel) were successful. This was

demonstrated with Fast-Fix 1 on a full size 66 ft crater. Holes were filled with sandy soil below the caps and had a CBR of about 4.

For Fast-Fix percolated through a bed of crushed rock, tire pressure fixed at 275 psi, and single wheel rolling load fixed at 29,000 lb, the following empirical equation was developed to predict the needed patch thickness:

$$h = \frac{290}{\rho^{0.5}\ CBR^{0.282}}$$

h = panel thickness, in.

ρ = repair material flexural strength, psi

CBR = California Bearing Ratio of base

(b) <u>Mortar- and rocket- damaged runways.</u>[A4] Based on the successful outcome of the just discussed tests at Elgin AFB during 15-24 August 1967, Fast-Fix was considered as a potential material to rapidly repair mortar- and rocket- damaged runways. Fast-Fix 1 and Fast-Fix 3 cements were used in this study to develop concretes compatible with conventional concrete-transit-truck mixing operations. Through laboratory and small scale (2 1/2 cu ft) mixer studies, the following mix proportions were recommended: (1) 4 parts Fast-Fix 1 to 3 parts sand to 9 parts crushed rock ($\lesssim$3/4 in.) using 35 percent mix water (based on the cement) and (2) 2 parts Fast-Fix 3 to 1 part sand to 3 parts crushed rock using 45 percent mix water. The recommended Fast-Fix 1 formulation gave a mix having a slump of about 11 in., which easily flowed into irregularities of the broken runway pavement and could be contoured to the slope of an existing runway. For Fast-Fix 1, 30-minute strengths of neat cement were 2030 psi in compression and 750 psi in flexure; for the recommended concrete, the strengths were about 1670 psi in compression and 480 psi in flexure.

Fast-Fix 3, neat, was about 1490 psi in compression and 770 psi in flexure; the concrete, 1280 psi in compression and 470 psi in flexure. Water content was held at 35 percent based on the cement for Fast-Fix 1, and at 45 percent for Fast-Fix 3, which means that the neat slurries, effectively, had more water. They could be safely mixed up to 10 minutes while the mixes with aggregate could only be mixed for 2 to 3 minutes. WR-1 retarder was used to lengthen the set times (0.1 percent = 20 minutes set time; 0.2 percent = 34 minutes; 0.4 percent = 65 minutes).

In small scale tests, both the Fast-Fix 1 and the Fast-Fix 3 formulations carried the single wheel load of 29,000 lb for a tire pressure of 275 psi, for patch thicknesses of 9 in. or greater over subbase of CBR = 3.5 or greater. For thinner patches, the Fast-Fix 1 formulation was superior and this was used for full scale tests (10 ft diameter, 4 ft deep crater) at Port Hueneme, California. A transit mix truck and also a truck mounted turbine mixer were used to provide the needed mixing. Patches of 6.25 in. or more thick all passed the required loading within 1 hour of starting the backfill.

(c) Special mixing and delivery equipment (Fast-Mix)[A2,A3,B10]. In order to mix and pump a Fast-Fix slurry in the requisite time to percolate around crushed stone in the top 12 in. of a full-scale crater (70 ft diameter), equipment had to be developed to mix and deliver 1000 gpm. In developing this mixer, a scale model mixer to deliver 35 gpm was first built and evaluated. The basic concept of this mixer incorporated a jet eductor mixer similar to those used in oil field cementing operations. To provide uniform control of slurry density, a solids metering feeder was incorporated into the design concept. During field testing, information was gained which led to the design of a new type of vertical jet mixer.

Design of the full-scale "Field Service Unit" was broken down into systems and subsystems(A3). (The reference should be checked for drawings and discussion.) A dual system, two units to deliver 1000 gpm each, was designed to check out various alternatives and give increased reliability. Mixing water was pumped using two 650 gpm centrifugal pumps. Water was ejected into the mixing cones through 20 spray nozzles. The walls of the vertical jet mixer were continuously bathed with water. Because of the quick-setting nature of the Fast-Fix cements, it was necessary to incorporate a flushing system for all pumps, slurry tanks, and lines. An auxiliary water pump and 3 flush hoses were included in addition to the main water flow lines. Two slurry distribution systems were incorporated, hoses and nozzle discharge. For a slurry discharge of 1000 gpm, about 125 to 130 cu ft/minute (125-130 sacks of cement per minute or about 12,500 lb/minute) of solids must be handled. Solids were delivered to a wedge-shaped hopper and conveyed using four 12 in. diameter feed screws, tied together with chain drives to operate in pairs. Each pair fed one of the jet mixers. Two 380 horsepower diesel engines supplied power. A 24 volt control system was developed to monitor slurry density, etc.

(7) Mix designs for Fast-Fix cements.

(a) Fast-Fix 1. Nosseir and Katona studied the use of Fast-Fix concrete as a structural material(B1). For concretes with an age of 1 hour, compressive strengths of up to 3300 psi can be achieved by the proper selection of constituents. Attempts to obtain higher strengths resulted in unworkably short set times and exorbitant cement contents. Design curves, based on laboratory data on 0.06 cu ft batches, are given which enable one to design a mix to have

a specified compressive strength and set time. From these design curves, two mixes were chosen to have compressive strengths of 2000 psi and 3000 psi and set times of 10 minutes and 12 minutes, respectively. See Table VII.

TABLE VII
FAST-FIX 1 MIX COMPOSITION AND PROPERTIES

	Mix 1	Mix 2
Nominal compressive strength, psi	2000	3000
Expected set time, min.	10	12
Sand-to-total aggregate ratio	0.6	0.6
Aggregate-to-cement ratio	3.00	1.11
Water-to-cement ratio	0.4	0.3

Fourteen 3 cu ft batches were made based on mixes 1 and 2. Compressive strengths averaged 1980 and 2910 psi, very close to the predicted values. Averaged set times were increased by 2 minutes in each case. Apparently the much increased batch size increased the set times slightly. Initial compressive moduli were 2.30×10^6 psi (Mix 1) and 2.39×10^6 psi (Mix 2). No aging effect on strength was noted for times from 15 minutes to 7 days. Average splitting tensile strengths were 9.7 percent of average compressive strengths for compressive strengths between 2000 and 3000 psi.

Nosseir and Katona also investigated the structural behavior of reinforced concrete beams made with Fast-Fix 1 cement[B2]. Throughout the test program, brittle shear and compressive failure modes occurred as predicted. In addition, beams which were predicted as borderline cases between brittle and ductile failures failed in a ductile tensile mode. This trend is desirable as it insures the ductility required for safe designing. Comparing the

performance o. two Fast-Fix beams with "duplicate" beams made of portland cement concrete revealed that the ultimate strength of the Fast-Fix beams was at least as high as that of the portland cement concrete beams. The stiffnesses of beams made with portland cement were slightly higher than those of the Fast-Fix beams.

Included in the studies of Fast-Fix 1 and Fast-Fix C-1 cement concretes for the rapid repair of mortar- and rocket- damaged runways was a report of ballistics tests at Camp Pendleton on 14 March 1968 of a Fast-Fix 1 concrete wall.(A4) The wall was 7 ft high, 8 ft long and 10 in. thick. Instead of the 4 parts cement: 3 parts sand: 9 parts coarse aggregate recommended for the runway patch, a 2:3:5 mix was selected for economy. The wall was poured in the morning; forms were removed 30 minutes after pouring; testing took place in the afternoon. It was tested with an M-14, an M-16 30-caliber machine gun, an M-79 grenade launcher (antipersonnel), a 50-caliber machine gun, and an LAW (52 mm, light antitank weapon, rocket propelled shaped charge). Except for the LAW, several rounds from each weapon were fired into the wall. Gunnery officers agreed that the material was at least as effective as portland cement as a bunker material and would be highly desirable when structures, such as bunkers, are needed quickly. It was recommended that the Fast-Fix formulation be retarded, perhaps to a set time of 30 minutes, to permit additional handling time. This could easily be done by using a small quantity of WR-1 retarder at a slight sacrifice in strength.

(b) Fast-Fix C-1. Griffin studied mix designs for Fast-Fix C-1 cement concrete compared with the properties of Fast-Fix 1 cement concrete.(B3) In addition tests were conducted to determine the effect of sodium citrate retarder (WR-6) on the setting time and strength of Fast-Fix C-1 cement concrete. For an aggregate-cement ratio

of 1.5 or lower, both concretes compare closely in strength, with Fast-Fix 1 concrete being slightly higher. For an aggregate-cement ratio higher than 1.5, Fast-Fix 1 concrete is definitely superior at an age of 1 hour. Fast-Fix C-1 cement concrete continues to gain strength with age, whereas Fast-Fix 1 concrete apparently achieves maximum strength within 1 hour. Air cured Fast-Fix C-1 concrete is much stronger than fog cured Fast-Fix C-1 concrete at an age of 28 days. (For comparative materials, compressive strength in air at 1 hour = 2450 psi; fog cured for 28 days, 3470 psi; and air cured for 28 days, 5480 psi.) WR-6 retarder (apparently at a concentration of 0.32 percent based on the cement) extends the setting time of Fast-Fix C-1 concrete by an amount varying from 17 to 22 minutes; decreases the compressive strength by less than 10 percent at an age of 1 hour for an aggregate-cement ratio of 1.5; and slightly increases the strength at an age of 28 days.

Some further data on the increase in strength with time of Fast-Fix C-1 mortar and concrete is given by the following short tabulation.(B10)

Material	Cement: Sand: Rock	Water-Cement Ratio	Flexural Strength psi			Compressive Strength psi		
			30 min	2 day	7 day	30 min	2 day	7 day
Morta.	1:1	0.30	546	744	--	2320	2740	--
Concrete	1:1:2.45	0.32	400	--	875	1800	--	6360

(8) Highway patch trials.(B7) In December 1968, the Tri-City Construction Company of Kansas City, Missouri, teamed with the Western Company in cooperation with the Kansas State Highway Department, to pour two patches on a busy section of the Turner Diagonal in Wyandotte County.

One patch was opened to traffic in 20 minutes. Fast-Fix C-1 was used for the repair.

c. As modeling materials.

(1) Mix designs.[B4] Ultracal 30 (U. S. Gypsum Co.) and Type III portland cement ("Velo"-Monolith Portland Cement Co.) were used to develop "models" for portland cement. In the appendix to this reference, Hydro-Stone (U. S. Gypsum Co.) is shown to compare fairly closely with Ultracal 30. Table VIII shows mix proportions and properties for several Ultracal 30 gypsum concretes. Using the "Velo" cement, it is shown that by varying the water-cement ratio from 0.33 to 0.97 and the aggregate-cement ratio from 1.04 to 5.30, compressive strength can be varied from 13,000 psi down to 2940 psi. The water-cement ratio is the chief variable to obtain a desired compressive strength. The aggregate-cement ratio is juggled to give workable mixes.

Gypsum concrete reaches a plateau in compressive strength vs. age within 3 days after casting. After a day, the strength begins to increase again because of moisture lost to the atmosphere. To extend this period of stable strength for a period of several days, specimens were sealed with shellac.

It is recommended that specimens for compressive testing be capped with "Mineralead" (Atlas Mineral Products Co., Mertztown, Pennsylvania).

(2) Compressive dynamic tests.[B15] The same materials, aggregate gradations, and procedures as described in reference B5 (see Section III C.2.c.(4), following) were used to cast test cylinders. Solid and hollow cylinders were tested. The solid cylinders were 1 1/2 in. in

TABLE VIII

AVERAGE RESULTS FROM COMPRESSIVE, FLEXURAL, AND SPLITTING TENSILE TESTS ON GYPSUM CONCRETE(1)

Water-Cement Ratio (by weight)	Aggregate Cement Ratio (by weight)	Compressive Strength f'_c (2) (psi)	Splitting Tensile Strength f'_{sp} (3) (psi)	Flexural Strength f'_f (psi) Small(4) Beam	Flexural Strength f'_f (psi) Large(5) Beam	Initial Tangent Modulus of Elasticity E_c (psi x 10^6)	Strain at Maximum Compressive Stress, ϵ_c (in./in.)
			No. 4 Aggregate				
0.225	0	6590	-	-	-	3.01	3160
0.260	0.35	4900	441	789	718	-	-
0.300	0.76	4080	-	-	-	2.80	-
0.325	1.00	3510	257	-	-	2.45	2600
0.400	1.60	2530	200	416	403	-	-
0.500	2.30	1730	-	-	-	2.15	1480
0.600	2.95	1380	-	-	-	-	-
0.700	3.58	960	-	-	-	-	-
			No. 30 Aggregate				
0.225	0	5700	-	-	-	-	-
0.280	0.30	3990	413	-	-	2.31	2120
0.335	0.60	3210	-	-	-	-	-
0.390	0.92	2980	-	-	-	2.67	1780
0.445	1.28	2370	-	-	-	-	-
0.500	1.50	1530	-	-	-	2.14	970

(1) Average results from three specimens except where noted otherwise.

(2) 1 1/2 x 3 in. cylinders for No. 4 aggregate; 1 (OD) x 5/8 (ID) x 2 in. cylinders for No. 30 aggregate.

(3) 1 1/2 x 3 in. cylinders for No. 4 aggregate; 1 x 2 in. cylinders for No. 30 aggregate.

(4) Width - 1 1/2 in., depth - 1 1/2 in., span - 4 1/2 in.

(5) Width - 1 1/2 in., depth - 3 in., span - 9 in.

diameter and 3 in. high. The maximum aggregate size was "No. 4." Type III portland cement concrete cylinders were aged 18 days; Ultracal 30 gypsum concrete cylinders were aged 2 days. The dynamic testing machine was a pneumatic-hydraulic machine. Air pressure in hydraulic accumulators supplied the energy. The cross head velocity was varied by regulating the rate of flow of hydraulic fluid on the bottom of the main piston. Load cell, head movement, and strain readings were automatically recorded on tape and observed on an oscilloscope during a test. Table IX gives some average results (four specimens each) for microconcrete and gypsum concrete specimens.

(3) Dynamic testing, uniaxial tension.(B6) Ultracal 60 and Hydro-Stone gypsum cement, and high early strength and ordinary portland cement were used. Specimens for dynamic testing were circular bars 0.9 to 1.2 in. in diameter and 18 to 58 in. in length. Static tensile strength specimens were 2 in. long bars cut from these specimens and tested in compression (cylinder tensile splitting strength). The dynamic tester was a special holding device developed and built by Melpar. A compressive pulse was generated by the longitudinal impact of two metal bars and applied to one end of the test specimen. The compressive pulse was reflected at the free end of the specimen into a tensile pulse and caused fracture in tension near the mid-length of the specimen. This took about 20 microseconds.

Ultracal 60 batches contained 3800 gm cement to 1482 gm water; Hydro-Stone batches, 2700 gm cement to 900 gm water. Cement and water were mixed under a vacuum. Ultracal 60 specimens were tested after 13 to 19 days of air drying; Hydro-Stone specimens, after 41-55 days, except for three specimens tested at 15, 16, and 24 days. High early strength cement specimens were cured under water for

TABLE IX

DYNAMIC COMPRESSIVE PROPERTIES FOR TYPE III PORTLAND CEMENT CONCRETE CYLINDERS AND GYPSUM CONCRETE CYLINDERS

Microconcrete Cylinders				Gypsum Concrete Cylinders			
Stress Rate psi/sec	Compressive Strength psi	Secant Modulus psi (1)	Strain (2) %	Stress Rate psi/sec	Compressive Strength psi	Secant Modulus psi (1)	Strain (2) %
35 (3)	4110	2.28×10^6	0.39	35 (3)	4030	2.00×10^6	0.30
2.2×10^4	5220	2.64×10^6	0.38	1.1×10^4	4260	2.54×10^6	0.26
2.75×10^5	5360	2.74×10^6	0.39	4.7×10^5	4640	2.62×10^6	0.30
5.25×10^6	6100	2.64×10^6	0.40	4.6×10^6	5390	2.22×10^6	0.41

(1) Taken between 0.0 and 0.1% strain
(2) To maximum load
(3) "Static" rate of stressing

7 days and then in air on a rack for 14 days; ordinary portland cement specimens, 14 days under water and 14 days on the rack. Table X gives strengths found.

TABLE X

COMPARATIVE DYNAMIC PROPERTIES OF GYPSUM AND PORTLAND CEMENTS

Material	Static Tensile Strength psi	Dynamic Tensile Strength psi	Dynamic Modulus of Elasticity psi
Ultracal 60, series 1	634	-	1.95×10^6
Ultracal 60, series 2	570	2140	1.86×10^6
Hydro-Stone	981	2600	2.40×10^6
High early strength portland cement	654	1680	5.41×10^6
Ordinary portland cement	546	1400	4.93×10^6

Information of the type generated by this investigation is essential if fracturing of rock by large explosions is to be predicted by observations of small scale model explosions.

(4) Geomechanic model studies.(B5) In this study modeling techniques were developed. The plaster-of-Paris used was Red Top No. 1 white molding plaster (U. S. Gypsum Co.). This is 97-98 percent $CaSO_4 \cdot 1/2\ H_2O$. Fillers used were: kaolinite ("Kaolin NF", 400 clay, code 5643, Mallinckrodt Chemical Works, St. Louis, Missouri), diatomaceous earth ("Hyflow Supercell", Johns Manville Co.), fine Wabash sand, and fine Sangamon sand. Anhydrous dibasic sodium phosphate (Na_2HPO_4) was used as a set retarder.

A 2:1:2 mixture of water:plaster of Paris: kaolinite sets in 11 to 12 minutes (a 2:1 water-cement ratio was chosen to give a low unconfined strength of between 200 to 500 psi). The set time can be increased to about 60 minutes by the use of 0.5 percent of the retarder based on the cement. Specimens were oven dried at 110°F until all free water was removed. (Oven drying gypsum based specimens at 115°F and 145°F is not too bad, but drying at 170°F and 225°F, as indicated by a lower equilibrium weight ratio, starts dehydrating the strength producing dihydrate back to the semihydrate.)

Previous investigators using gypsum plaster for modeling have stated that the unconfined compressive strength could be controlled by varying the water-plaster ratio. (Increasing the water-plaster ratio lowers the strength.) This is not a completely valid assumption. One batch with a slightly higher mix water ratio than two cther batches still had a higher compressive strength; one batch had twice the mix water of another batch but the compressive strengths were about the same. Apparently the significant variable influencing the cohesion is the density of the gypsum matrix. Too much mix water when it evaporates gives a porous structure, a low bulk density, and low cohesion. Obtaining the same lowered matrix density using a bulking material and lower mix water content will give the same lowered strength. A batch with higher mix water when compacted to a greater density with less air voids will have a greater bulk matrix density and a higher strength in spite of the higher mix water content.

All data so far indicate that two strength parameters, cohesion and internal friction, can be controlled independently by varying the gypsum matrix density and the density of the sand grain structure.

Cylinders for testing were capped with Hydrocal. To obtain the lowest possible coefficient of friction between compression machine platens and the specimens, two sheets of 0.005 in. thick Teflon placed between two sheets of wax paper were used. From the literature, coefficients of friction for commonly used dry lubricants are:

Graphite	0.10 - 0.19
Molybdenum disulfide	0.05 - 0.15
Teflon	0.03 - 0.04

d. Miscellaneous mixes.

(1) F-181-R DAKRON (Ranco Industrial Products Corporation).[B8b,B9] A grouting mixture, having a water-cement ratio of 0.349, allowed a working time of 10 minutes had compressive strengths of 1810 psi in 30 minutes and 3250 psi in 1 hour.

(2) High portland cement-gypsum mixes.[B8a,B8c] Evidence of the accelerating effect of gypsum cem nt addition to portland cement is shown by the following three grouts:

Composition (parts by volume) Portland cement	Hydro-Stone	Water	Compressive Strength psi (at 16 hours)
1	1	1 1/2	600
1	3	2	1000
1	4	2 2/3	1400

The following show how increasing amounts of plaster-of-Paris improve early strength but lower later strength:

Composition (Wt. %)					
Type III Portland Cement	Plaster of Paris	Water-Cement Ratio	Compressive Strength psi		
			1 day	3 days	7 days
95	5	0.5	1740	3330	5260
90	10	0.5	1870	2530	2900
80	20	0.5	2000	2280	2070

A mixture of 30 to 70 parts portland cement, 10 to 36 parts anhydrous calcium sulfate, and 20 to 40 parts kaolin is claimed as a quick-setting composition.[B16]

(3) Gypsum - other cement mixes, foreign.[B12,B12,B14] These three *Chemical Abstracts* refer to Russian studies showing that gypsum additions to various other cements affect strength and accelerate set time.

3. High Alumina Cements (H.A.C.). High alumina cements have been proposed and successfully used as quick setting, early strength materials. Strength development in 24 hours is equivalent to that of portland cement in 28 days. H.A.C. perform particularly well where ambient temperatures do not exceed 73°F.

a. Composition.[B17,D2] The main ingredient of H.A.C. is monocalcium aluminate ($CaO \cdot Al_2O_3$), usually obtained by fusing or sintering limestone and bauxite. There is usually quite a high percentage of tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$), also. The color will vary widely according to the manufacturing process or the type of

bauxite used. The chief factors, determining the color of the cement powder, are the amount and the state of oxidation of the iron compounds present: ferrous compounds tend to be very dark colored; ferric compounds tend to be brown or rust colored. The iron oxide content can be as high as 18 percent. Up to a concentration of 10 percent, this tends to increase the hydraulic strength of the cement.

b. Typical trade names and set times.(D2) Some of the names by which H.A.C. are known around the world are: "Lumnite Cement" (The Atlas Cement Co.), U.S.A.; "Ciment Fondu" and "Lightning," England; "Fondu Lafarge," France; "Rolandshütte,"* Germany; "Istrabrand," Yugoslavia; "Citadur," Hungary and Czechoslovakia; "Fundido Electroland," Spain; "Alcement Lafarge," Scandinavia; and "Asahi Fondu" (Asahi Glass Co., Ltd.), Japan.

The American H.A.C. contains a retarder and has an average initial setting time of about 8 hours. British H.A.C., by specification, has a setting time between 2 and 6 hours after gauging, with the average about 4 hours. French H.A.C. sets slightly faster than most of the others. High mix temperature or contamination with lime, plaster, portland cement, etc., can cause genuine quick setting. The development of strength in a portland cement mix is slow after the initial set occurs; in H.A.C., it is very rapid.

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*An advertisement in Brick and Clay Record, p 26, Vol. 158, No. 1 (January 1971) reviews that "Rolandshuette" Calcium Cement is now available in the U.S.A. from Calcium Aluminate Cement Corporation, 120 Wesley Street, South Hackensack, N.J. 07606.

c. Some physical properties of grouts, mortars, concretes.

(1) Compressive and flexural strength. A French H.A.C. concrete developed a compressive strength of 3410 psi and a flexural strength of 333 psi in 6 hours. (Cement content was 590 lbs/cu yd and water-cement ratio was 0.50. Cure was at 64°F.) In 1 day, these strengths were 5670 psi and 428 psi, respectively. For the same mix and cure conditions, rapid-hardening portland cement concrete has 0 strength at 6 hours, and 1720 psi compressive strength and 189 psi flexural strength at 1 day.(D2)

Bendinelli(B25) found that a "Ciment Fondu" grout made with a water-cement ratio of 0.48 had a pumping time of about 15 minutes. Two inch cubes had compressive strengths of 7020 psi in 18 hours, 8380 psi in 74 hours, and 9020 psi in 7 days. He also reports compressive strengths at 3 days for neat "Lumnite Cement" of 12,710 psi compared to 8050 psi for neat Type III cement. Samples were cured at 100 percent R.H. and 73 ±2°F.

Roberts(B33) restrained slab strips against longitudinal expansion by filling the 3/16 in. gaps between slabs with a 1:1 mortar mix of H.A.C. and sand (screened to pass a No. 25 sieve). Water-cement ratio was 0.35. The cube strength of this mortar mix was at least 10,000 psi in 24 hours.

(2) Paste viscosity.(D2) Pastes made from most H.A.C. appear wetter than portland cement pastes of the same water content and the difference is greatly accentuated at the lower water-cement ratios. This difference is even more marked when a comparison is made with rapid-hardening portland cement. An H.A.C. paste with a water-cement ratio of 0.36

had a lower "viscosity" than a plasticized (1 percent) rapid-hardening portland cement paste with a water-cement ratio of 0.49.

(3) Elastic moduli.[D2] The moduli of the aggregates are generally higher than that of the cement paste, consequently the moduli values will vary with the type of aggregate and with the aggregate-cement ratio. Except at very early ages, the effect of water-cement ratio is small. For 1:2:4 concretes made with British H.A.C. the dynamic modulus varied from about 6.7 x 10^6 to 7.4 x 10^6 psi for water-cement ratios between 0.45 and 0.60, the higher w/c giving the lower value.

The static modulus, when derived from the load-deflection curve of beams, approaches the dynamic modulus. Tests carried out on a very large number of prestressed concrete beams made with British H.A.C. showed moduli at 1 day of 5.0-7.0 x 10^6 psi with an average value of nearly 6.0 x 10^6 psi. The corresponding H.A.C. concrete cube strength of 1 day was over 9000 psi.

(4) Poisson's ratio.[D2] The following values were obtained on water stored 1:2:4 gravel concretes (540 lbs cement/cu yd).

Age	6 hours	1 day	7 days	28 days	6 months
Poissons' ratio	0.30	0.25	0.23	0.23	0.21

Poisson's ratio was calculated from the ultrasonic pulse velocity and the dynamic modulus of elasticity.

(5) Bond to steel.[D2] There is little difference between the bond strength of H.A.C. to steel and

of portland cement to steel except in the rate of bond development. The bond strength of H.A.C. at 1 day is equivalent to that of rapid-hardening portland cement at 7 days and to ordinary portland cement at 28 days.

(6) Thermal expansion.[D2] The thermal expansion of any concrete is chiefly dependent on the nature of the aggregate, but neat H.A.C. is considerably lower than portland cement. Some average coefficients of linear thermal expansion (32°F to 104°F) are 7.9 x 10^{-6} per °F for neat H.A.C. and 12.6 x 10^{-6} per °F for neat portland cement. For 1:6 gravel concretes, these values are 7.5 x 10^{-6} and 7.3 x 10^{-6}, respectively. These values are for air stored specimens.

d. Effect of temperature on setting time.[D2,D5] The effect of temperature on the time to set is anomalous. For the temperature range from about 34°F to 86°F, setting time is the shortest at about 50°F. As the temperature rises above 50°F, set is usually progressively retarded, until a maximum set time is reached at about 86°F. Above 86°F, the setting time is reduced rapidly as the temperature increases.

The rapid hydration of H.A.C. even at 32°F is worthy of note. In 6 hours, a French H.A.C. concrete developed compressive strengths of 3410 psi at 64°F, of 3000 psi at 54°F, of 2360 psi at 43°F, and of 767 at 32°F. At 16 hours, these strengths were 5510 psi, 5100 psi, 5050 psi, and 4630 psi, respectively.

e. Effect of temperature and humidity on hydration.[B17,D5,D2] Probably the main problem in using H.A.C. is that two types of crystalline hydrated structures may be formed. The ones first formed, especially at lower temperatures are metastable hexagonal hydrates, having densities less than 2.0 g/cm³. The one which may be

formed later is the more stable cubic hydrate having a density of 2.5 g/cm³. This large increase in density in a "set" concrete can result in increased porosity, internal strains, and a large decrease in strength.

In the presence of water, the rate of change of the hexagonal hydrates to the cubic hydrate is very slow below 77°F, but it is accelerated by higher temperatures or high pH values. With the absence of moisture at high temperatures, there is essentially no change to the cubic form and consequently no strength loss. The use of a lower water-cement ratio in the mix decreases the crystalline change and the effect of a crystalline change. (At a w/c ratio of 0.6 the normal 1 day compressive strengths of the hexagonal hydrates vary between 5700 psi and 6700 psi; the fully converted cubic hydrate compressive strength is about 2000 psi. At a w/c ratio of 0.3, the hexagonal hydrates vary from 9300 psi to 10,300 psi; the fully converted cubic hydrate is about 9200 psi.) H.A.C. concrete exposed for 20 years in sea water, found to be fully converted to the cubic hydrate, showed no loss in strength. It has been found that if the hexagonal hydrates are allowed to mature under cool conditions, even for a few hours, their rate of conversion under subsequent hot, wet conditions is reduced.

The data in Table XI obtained by Miller on "Ciment Fondu" mortar cubes show the deleterious effect of wet aging at 100°F compared to 60°F and 73°F.[B24]

Two Russian references discuss the effect of curing conditions and phase transitions on the strength of alumina cement concrete.[B27,B28] One claim for specimens cured for 3 days at temperatures between 32°F and 108°F, and then aged at room temperature, that the compressive strength of specimens cured at 75°F to 86°F were always lower compared to specimens hardened at lower or higher temperatures.[B27]

TABLE XI

EFFECT OF STORAGE CONDITIONS ON STRENGTH OF HIGH ALUMINA CEMENT MORTARS (CIMENT FONDU)

Age, days	Compressive Strength psi for storage at 60°F	73°F	100°F
1	7110	7420	6340
3	7650	9280	3720
7	8780	9700	4110
28	9880	10,340	3840

Nctes:

1. Mortar made from 1 part cement to 3 parts sand. Sand was 50 percent standard and 50 percent graded. Water-cement ratio was 0.40.
2. Two inch mortar cubes made and tested per ASTM Method C109-64. Compressive strength averages reported for three cubes.
3. For the first 24 hours, specimens were left in their casting molds and the 73°F specimens put in a moist cabinet; the 60°F and 100°F specimens sealed in plastic bags. After removal from the molds at 24 hours, all specimens were stored in lime-water at the designated temperatures.

f. Set accelerators. As with portland cement, a small proportion of certain substances can be added to H.A.C. to accelerate or retard set, entrain air, reduce permeability, increase workability, and otherwise modify some of the concrete properties. These substances may be added during grinding or at the mixer. The various types of H.A.C. may give different reactions with the same additive.[D2]

(1) Mixes with portland cement. Pcrtland cement acts as an accelerator of set for H.A.C. and vice-versa. The setting times observed also depend on other factors such as water-cement ratio and temperature. Usually much less portland cement can be added to H.A.C. before a very fast or flash set is produced than vice-versa, and the set of mixes rich in H.A.S., therefore, tends to be more sensitive to small changes in the proportion of portland cement. Curves at rate of set versus composition show flash set occurring for H.A.C. concentrations between about 40 percent and 85 percent (portland cement from 15 percent to 60 percent). The two cements should preferably be mixed in the dry form but, if they are blended as slurries, the minor constituent should always be stirred into the major constituent, since the reverse procedure results in a flash-setting composition before addition is complete.[B10,D2]

A mix consisting of 1.5 parts of ordinary portland cement to 1 part of H.A.C. may set in 5 to 15 minutes and give a mortar or concrete strength of about 1000 psi within an hour. The faster the set obtained, the lower is the ultimate strength.[D2] A mixture of 60 percent portland cement:40 percent H.A.C. may have a strength of 800 psi in less than an hour and of 1500 psi in 24 hours; 100 percent H.A.C. may have no strength in 5 hours, but a strength of 7000 psi in 24 hours; 100 percent portland cement may have no strength for 8 hours and less than 1000 psi in 24 hours.[B19] The temperature of cure for these blends as for 100 percent H.A.C. can affect the ultimate strength as shown by Table XII for specimens cured at 60°F and 100°F.[B19]

Dolch and McLaughlin in a consultants' report to the Peasley Study[A11], previously reported, suggest for the rapid repair of bomb induced craters that

TABLE XII

EFFECT OF TEMPERATURE ON THE STRENGTH DEVELOPMENT OF MIXTURES OF PORTLAND CEMENT AND HIGH ALUMINA CEMENT

		Compressive Strength, psi	
Blend	Age, Days	Cured @ 60°F	Cured @ 100°F
80% Portland cement	1	490	1300
20% H.A.C.	3	750	1850
	7	1740	1880
	28	2760	2610
	56	3480	2960
70% Portland cement	1	650	960
30% H.A.C.	3	840	1040
	7	1450	1220
	28	2050	2260
	56	2900	2400
60% Portland cement	1	850	320
40% H.A.C.	3	960	350
	7	1510	410
	28	1970	780
	56	2440	1220
50% Portland cement	1	1450	1220
50% H.A.C.	3	1550	1100
	7	1680	980
	28	1830	990
	56	1910	990

1. Specimens were neat cement. Water-cement ratio equaled 0.45.

2. Control cubes were cured at 60°F and 90-100% RH; test cubes were cured for 30 minutes at 100°F and 90-100% RH, then under water at 100°F.

consideration be given to a macadam-like construction of the upper layer and that the macadam stone be bound with a slurry of portland and H.A.C. A mixture of 2/3 portland cement and 1/3 H.A.C. (Lumnite) with a water-cement ratio of 0.6 produced a slurry that poured easily and would penetrate and infiltrate all of the void space in a container filled with 3/4 to 1/2 in. gravel. The slurry was thin enough to pour for a period of 5 to 10 minutes and set in about 20 minutes. At 2 hours, the penetrated aggregate had a compressive strength of 600 psi. More portland cement and less H.A.C. in the mix would give a slower set, lower strength at 2 hours, more strength later. A lower water-cement ratio would give higher strength but lower fluidity.

Calcined alunite rock was used as an accelerator of the setting and hardening of slag and pozzolan portland cements.[B29] Alunite containing more $CaSO_4$ produces a greater acceleration. This ensures a higher initial strength of the cement. The addition of alunite to slag portland cement increases the 1 day strength by 5 to 88 percent and reduces the 28 day strength by 0 to 11 percent. Pozzolan cements plus alunite show an increase in 1 day strength of 32 to 257 percent and a decrease in 28 day strength of 8 to 27 percent. Slag and pozzolan portland cement with 7 to 10 percent alunite expand from 0.1 to 0.3 percent during 1 to 2 days of curing. Fast-setting concretes were prepared with a cement:sand:aggregate ratio of 1:2:3. Concrete with a 20 percent alunite suspension had strengths after 1 hour, 1 day, 7 days, and 28 days of 170 psi, 1820 psi, 4340 psi, and 5120 psi; without alunite these strengths were 0 psi, 1280 psi, 3610 psi, and 4190 psi, respectively.

(2) Mixes with other cements. The Highway Research Board bibliography of "Recent Russia Research on Cement and Concrete"(D3) presents several mixes with fast cures and good early strengths.

(a) Aluminate cement. This is prevailingly calcium aluminate with set starting in about 30 minutes and ending in 12 hours. Strength at 1 day is between 3560 and 6400 psi.

(b) Gypsum-aluminate expansion cement. This is a mixture of aluminate cement and natural gypsum (dihydrate). Set starts in 20 minutes and ends in 4 hours. Strength at 1 day is between 3560 and 6400 psi.

(c) Anhydrite-alumina cement (AG cement). This is a mixture of 70 to 75 percent aluminate cement and 25 to 30 percent anhydrite. Set starts in 20 minutes and ends in 5 hours. One day strength is 4300 psi.

(d) Water-impermeable expansion (VRTs) cement. This cement is a mixture of aluminate cement, gypsum, and highly basic calcium aluminate. Set starts in 4 minutes, ends in 10 minutes. A 1:3 cement-sand mortar has a strength of 1070 psi in 12 hours; 4300 psi in 3 days, and 7100 psi in 28 days. The mortar is impermeable to water at 5 atmospheres and expands from 1/2 to 1 percent on cure.

(e) Water-impermeable, non-shrinking cement (VBTs). This cement is a mixture of aluminate cement, gypsum hemihydrate, and slaked lime. Set starts in 1 minute and ends in 10 minutes. There is no shrinkage for air hardening. The material is impermeable to water. Strengths are 710 psi at 6 hours; 1780 psi at 12 hours; 3560 psi at 3 days, and 4270 psi at 28 days.

(3) Fully hydrated H.A.C.[D2] If some H.A.C. is fully hydrated, dried, reground to cement fineness, and then added to the original cement, the setting times are accelerated as shown in Table XIII.

TABLE XIII

EFFECT OF HYDRATED H.A.C. ADDITION ON SETTING TIMES OF H.A.C.

	Setting Times	
	Initial	Final
H.A.C. without addition	4 hrs 40 mins	5 hrs 30 mins
H.A.C. + 5% hydrated H.A.C.	3 hrs 25 mins	4 hrs 5 mins
H.A.C. + 10% hydrated H.A.C.	2 hrs 25 mins	3 hrs 15 mins
H.A.C. + 25% hydrated H.A.C.	10 mins	40 mins

(4) Miscellaneous materials.[D2,D5] Inorganic alkaline hydroxides, strong organic bases, alkali carbonates or silicates, dilute sulfuric acid, all accelerate set and initial strength development but at the expense of ultimate strength. A quick-setting plaster is made from H.A.C. + aluminum sulfate + calcium carbonate + hydrated lime.

An example of some retarders are ligno-sulfonates and aluminum chloride hydrate. Mixes with these materials usually produce high strength at later ages when they delay the setting time by several hours.

g. High strength additives.[B26] Additives such as sugar, sodium metaphosphate, magnesium hydrate ($MgSO_4 \cdot 7H_2O$), calcium ligninsulfonate, tetrasodium ethylene diaminetetraacetate have been used to increase the comopressive strength of aluminous cement slag by a factor of from 2 to 15.

h. Acid and base resistance.[D5] Acid resistance is broadly limited to solutions with a pH greater than 4. In practice it has been found that alumina cement-latex mixes show greatly increased acid resistance. They have given good service in contact with 5 percent sulfuric acid.

H.A.C. are not resistant to solutions of alkali hydroxides since the protective alumina gel is readily dissolved - unlike portland or supersulfate cement concretes. Excessive alkali in the cement may accelerate conversion of the hexagonal hydrates.

i. Examples of utility.

(1) Fast runway repair.[B20,B21,B22] The military airfield at Yokota, Japan, was badly deteriorated and had to be replaced. It was in active use, however, and long down times could not be tolerated. The suggestion was made to use H.A.C. In Japan, this was "Asahi Fondu." Repairs had to be made on Sundays; total down time to be limited to 12 hours. The cement manufacturer's technical representatives recommended that areas between construction points be limited to 400 sq ft and the slab thickness be limited to 18 ins. To carry Class A traffic (expected gear loading of 100,000 lbs) and with a subsoil "k" value of 150 psi/in., flexural strength had to be over 700 psi. The mix to give these strengths was determined to be: cement - 556 lbs, water - 211 lbs, fine aggregate - 1173 lbs, coarse aggregate No. 4 to 1 in. - 1128 lbs, and 1 in. to 2 in. - 1124 lbs. As chemical action during hydration is greatly accelerated with aluminous cement, the use of washed aggregate was necessary to insure a cohesive mix. Pours should be made at night if day time temperatures are expected to exceed 75 to 80°F.

Concrete was placed between 6 April 1969 and 12 July 1969. Data were obtained on 6 in. x 6 in. beams for all pours. On only one occasion, 1 June 1969, did the flexural strength fall below 700 psi. Compressive strengths were not obtained. No evidence of failure or deterioration had occurred by 7 January 1970. The runway has maintained its textured broom finish better than portland cement concrete. Water curing does not glaze the surface of aluminous cement concrete as it often does with portland cement.

(2) Thin concrete road patches.[B23] An investigation was made to determine how soon after pour thin mortar patches (1/2 in. thick) of concrete roadways could be reopened to traffic. Various cements were evaluated: ordinary portland cement (O.P.C.), O.P.C. plus 2 percent calcium chloride, rapid hardening portland cement (Ferrocrete), extra-rapid-hardening portland cement (417), high alumina cement, 90 percent H.A.C. + 10 percent O.P.C., and 80 percent H.A.C. + 20 percent O.P.C. The patch material was a 1:3 cement:sand mortar. Titanium dioxide, 5 percent based on the cement weight, was added to the mixes containing H.A.C. to tone the dark grey color to a medium gray. In curing thin patches, water loss by evaporation can be very high. A resinous curing compound was sprayed on the surface immediately after the patch was completed at the rate of 0.2 ℓ/m^2 (25 sq yd/gal). Polyethylene sheeting, supported on battens clear of the surface, was then placed over the patches and kept in position until just before the patch was opened to traffic. Inspections were made at 12 hours, 5 weeks, 9 weeks, 4 months, and 1 year after placing. Table XIV shows ages at which the patches were reopened to traffic and remarks based on the subsequent inspections. In laying Mix No. 4 (extra-rapid-hardening

TABLE XIV

DATA ON EARLY TRAFFICKING OF THIN H.A.C. CONCRETE PATCHES

Mix No.	Composition, Cements Used	Patch age when opened to traffic hours	Results
1	Ordinary portland cement (O.P.C.)	35 and 27	All patches were OK at 1 year. Suggests O.P.C. repairs could be used within 30 hours;
2	O.P.C. + 2% $CaCl_2$	29	$CaCl_2$ accelerated, probably much earlier.
3	Rapid-Hardening	34, 26, and 10	Ten hour patch showed wear of broom marks at 12 hours inspection; no further wear afterwards. Ten hours minimum; 20 hours probably OK.
4	Extra-Rapid-Hardening P.C. (417)	28, 9, and 6	Six hours OK.
5	High Alumina Cement (H.A.C.)	6	Slight crazing after 5 weeks but OK.
6	90% H.A.C. + 10% O.P.C.	5	OK
7	80% H.A.C. + 20% O.P.C.	4	OK

portland cement), it was noted that the mix tended to be very sticky and tended to be pulled out by the vibrating beam unless great care was taken. This mix also showed a tendency to bleed if overworked.

(3) Miscellaneous.

(a) Refractory concretes.(D2,D5) A concrete made with aluminous cement and a suitably graded refractory aggregate (such as chamotte and crushed fire-brick) is termed a refractory concrete and used for large-scale furnace or kiln construction. The advent of pure, white aluminous cements have extended the working temperature range so that certain castables are suitable for continued use at temperatures of 1800°C (3272°F).

(b) Cold weather concreting.(B17,B18,B19) Because of fast strength development at 32°F, H.A.C. has great potential for use in cold regions.

(c) Emergency military construction.(B17) H.A.C. seems to be the most suitable cementing material for all temporary, emergency military construction such as pavements for airfields and roads.

(d) Repair "pumping" road pavements.(B19) A slurry composed of 85 percent portland cement and 15 percent H.A.C., water-cement ratio of 0.60, pumped under the pavement stopped this action. The material begins to thicken in 10 minutes and is quite firm in 15 to 20 minutes. Compressive strength is over 3000 psi at 7 days. In the field the portland cement slurry was made first and H.A.C. slurry pumped into it.

4. Silico-Phosphate Cements.

a. Dental silicate cement.(B34) Wells in 1968 searched for inorganic materials that would set at low

temperatures and have compressive strengths significantly higher than portland cement products (maximum values about 10,000 psi). Dental silicate cements (principal ingredients are alumina powder, silica powder, phosphoric acid, and water) were the only materials that seemed interesting. Six month strength as high as 30,000 psi was reported. The American Dental Association requires that the setting time be within the range of 3 to 8 minutes; the manufacturer gives it as about 5 minutes. Experimental compressive strengths obtained on compressive specimens 1/4 in. in diameter and 1/2 in. long show 15,900 psi at 1 week for a purchased dental silicate cement and 13,400 psi for an industrial silicate cement furnished by the S. S. White Company. At 28 days, these same materials had compressive strengths of 15,900 psi and 17,100 psi, respectively. Two samples of portland cement grouts, same size specimens, had strengths of 10,800 psi and 11,400 psi at 30 days. The cost of dental compound as sold to dentists is about $5.50 per 1/2 ounce batch. No quotation was forthcoming from the S. S. White Company as to the cost for, say, a 100,000 lb lot.

b. Study to develop inexpensive compositions.[B35]

(1) Composition and reaction theory. A dental cement consists of a glass powder of suitable composition and solubility in phosphoric acid, mixed with a zinc buffered phosphoric acid solution (containing a small percentage of aluminum). Analyses of ten different commercial cements showed their approximate composition to be 42 percent SiO_2, 30% Al_2O_3, plus varying amount of CaO, Na_2O, NaF, CaF_2, CaF, and P_2O_5. Of these constituents, the most important, from the bonding or structural viewpoint, are CaO, Al_2O_3, SiO_2, P_2O_5, and the Zn^0 (in solution).

When phosphoric acids are reacted with alumino-silicate glasses, there is a strong reaction but not setting. A plastic, almost elastomeric, material results but it never develops hardness or strength. However, if Ca^{++} or another cation is present, setting occurs. Thus the bonding in dental silico-phosphate cements is the result of the breakdown of the amorphous glass structure with incorporation of cations (Ca^{++}, Na^{+}, etc.) and anionic complexes (SiO_4, AlO_6, AlO_4, PO_4) into the liquid. By a complex reaction mechanism, the anionic constituents polymerize, forming chains which are "cross-linked" with the positive cations. In addition to the "polymerization and cross-linking" bonding mechanism, a secondary mechanism is the direct crystallization of a phosphate compound.

(2) Raw materials evaluated. A large number of natural materials and manufacturing byproducts were evaluated such as various clays, vermiculite, sodium bentonite, dolomite, limestone, quicklime, fluorspar, feldspar, blast furnace fines, fly ash, wollastonite, calcined alumina and brown mud (high Ca and Si). A large number of C.P. grade reagent materials, containing the chemicals, were also obtained.

Two types of phosphoric acid solutions were used: (1) 86 percent H_3PO_4 was purchased from Allied Chemicals (this was diluted and buffered as desired); (2) a "commercial liquid" purchased from the S. S. White Co. (Based on an emission spectrographic analysis, this solution appears to be a very complex mixture of phosphates formed by reaction of ZnO and P_2O_5. Major constituents were P and Zn; minor constitutent was Al with traces of Mg, Fe, and Cu.)

(3) Study results. Six hundred and fifty formulations were investigated and 10 showed promise for application in highway patching. Mixtures of 90 percent wollastonite ($CaSiO_3$) and 10 percent blast furnace slag (7.38 percent Al_2O_3) with "commercial liquid" (liquid-powder ratio = 0.3) showed 1 day compressive strength of about 10,000 psi and a 5 minute set time. Mixtures of 100 percent $CaSiO_3$ with "commercial liquid" (0.25 liquid-powder ratio) had 1 day strengths over 8000 psi and a 60 minute set time.

"Commercial liquid" was used in the majority of the formulations tested. A couple examples are given to show that in comparable formulations 40 percent P_2O_5 + 5 percent $ZnCl_2$ + 5 percent $AlCl_3$ + 50 percent H_2O(?) and 50 percent P_2O_5 + 5 percent $ZnCl_2$ + 5 percent $AlCl_3$ + 40 percent H_2O(?) gave equivalent or better properties.

Phase II of this study underway at this time will better characterize these cements.

(4) Economics. The cost per 100 lb for the 90 percent $CaSiO_3$, 10 percent blast furnace fines formulation using the S. S. White "commercial liquid" is estimated to be \$21; but, if the buffered phosphoric acid is used, this cost is estimated to be \$4.00.

5. Very Fine Cements. Bennett and Collings[B37] point out that the fineness of portland cement is known to be an important factor affecting the rate of hardening. The effect of greater specific surface is to increase the rate of hydration so that the early strength is higher, although the later strength may be about the same. No strengths for 1 hour or less are reported, but the data in Table XV show the great superiority in strength at 8 hours for finely ground cement. This table also shows the high early

TABLE XV

COMPRESSIVE STRENGTHS vs. TIME FOR
SELECTED CEMENT CONCRETES

Cement Type	Compressive Strength, psi			
	@ 8 hrs	@ 16 hrs	@ 24 hrs	@ 28 days
S	3,350	7,800	9,100	10,950
R	550	3,350	4,850	8,050
O	100	650	2,150	[illegible]50
C	2,300	4,050	5,300	10,600
H	9,650	11,050	11,400	14,000

Notes:

S = Special cement; specific surface = 7,420 sq cm/g

R = Rapid-hardening portland cement; specific surface = 4,900 sq cm/g

O = Ordinary portland cement; specific surface = 2,770 sq cm/g

C = Rapid-hardening portland cement + 2% interground $CaCl_2$

H = A high alumina cement

1 = aggregate: cement ratio = 3:1 to permit low water: cement ratio

2 = water: cement ratio = 0.35

strength development of a high alumina cement, previously treated. Reducing the fineness of the cement reduces the workability at equal water-cement ratios. At the same workability, the fine cement mortar is superior. A 5 year field trial of precast concrete members made using this special fine cement showed it to be superior to ordinary or rapid-hardening portland cement cast in situ.

Brunauer, et al,(B36) also report on the attainment of high early strengths with finely ground cements. They ground Type I cement clinker to specific surface areas of 7000 to 9000 sq cm/g using various hydrophobic grinding aids. Mixes were made up using lignosulfonate and K_2CO_3. Various mix consistencies from "sets in the mixing chamber" to "flows freely into the mold" were obtained. One day compressive strengths ranged from 300 psi to 14,000 psi; 7 day strengths, from 8300 psi to 18,900 psi; and 28 day strengths from 11,200 psi to 29,700 psi. One mix gave a compressive strength of 3000 psi in 9 hours and 13,000 psi in 19 hours. Type II cement also shows rapid strength gain and high strength attainment when fine ground using 0.5 percent diethyl carbonate as grinding aid. A mix containing 0.5 percent lignosulfonate and 0.5 percent K_2CO_3 had a compressive strength of 10,000 psi in about 30 hours; 20,000 psi in about 70 hours; and 30,000 psi in about 150 hours.

The Highway Research Board's annotated bibliography, "Admixtures for Highway Concrete,"(D4) lists a couple of references as to the efficacy of cement fineness: (1) in their reference B375, "Fine grain size and high $3CaO \cdot Al_2O_3$ content also increases the setting speed of cement," and (2) in their reference B383, "Quick-setting portland cement of normalized mineralogic composition is the only suitable material for emergency work. This cement brand has to be ground to the fineness of 5000 sq cm/g with a 2.5 to 3 percent addition of $CaCl_2$."

Abstracts from foreign research also indicate that particle size distribution and very fine cements will cause an early gain in strength: (1) the strength of concrete depends on the 3-30μ diameter fractions, it should be 40-50 percent in ordinary and 70 percent in high initial strength cements, the high initial strength is assisted by the 0-3μ fraction;[B38] (2) mechanical strengths of the cements investigated increased the finer the cement particle size and the higher its content of fine iron particles;[B39] (3) a linear relationship exists between cement strength and the hydrated amount of cement, calculated from particle size distribution with the aid of published information as to depth of hydration;[B40] (4) quick-setting cements having specific surfaces of 3000 sq cm/g and 4 percent gypsum addition were obtained from the two factories, concrete strength was considerably increased by increasing the fineness of the grains to 4000 to 5000 sq cm/g, compressive strength at 1 day was three times that of ordinary cement and was 47 percent of the 28 day strength;[B41] (5) Osaka Cement has developed a quick-curing cement that achieves maximum strength in a day when conventional cements take a week, the new cement features smaller granules than conventional cements.[B42]

6. Accelerating Admixtures. Many chemicals and combinations of chemicals, both organic and inorganic, have been observed to either retard or accelerate the set of cement mixes. Some of these chemicals have been noted during the previous discussion of quick-setting cements. This section will survey accelerating chemicals, especially as they pertain to portland cements.

a. <u>From Highway Research Board annotated bibliography "Admixtures for Highway Concrete."</u>(D4)

This bibliography contains 461 references in "Part B - Accelerating Admixtures," covering the time period from March 1885 to March 1962. (On line "B-numbers" refer to references in this bibliography.)

(1) <u>Calcium chloride.</u> $CaCl_2$ is referred to in the first reference (English Patent 2886)(B1) and is the one chemical most often mentioned in subsequent references. There is not always agreement as to the effect of $CaCl_2$, especially in early references; e.g. reference B5 says that small amounts of $CaCl_2$ retard set, large amounts accelerate; while reference B61 says that small amounts decrease set time, large amounts increase set time. The general concensus is, however, that $CaCl_2$ tends to accelerate the rate of hardening and to protect against freezing until set (B453), that $CaCl_2$ is one of the safest and least expensive of many known accelerators (B341). $MgCl_2$ (B28) and $BaCl_2$ (B102) are treated as somewhat equivalent to $CaCl_2$ while $BaCl_2$ (B102) is stated to be deleterious as regards set times. It is also claimed that $CaCl_2$ reduces the detrimental effect of organic matter in sand or concrete (B217).

Tests on 10 year old treated concrete in France, Belgium, and Sweden showed that 2 percent $CaCl_2$ produced no reduction in ultimate compressive strength, no corrosion of steel reinforcement, and no additional efflorescence (B237). For air-entraining concretes, cured at 40°F, strengths were increased for all ages up to 1 year by the addition of $CaCl_2$, with maximum results for a concentration of 3 percent; cured at 70°F, maximum results occurred at 2 percent $CaCl_2$ addition (B246).

Various mixes containing $CaCl_2$ are given for producing quick-setting cements: 0.17 percent anhydrous $AlCl_3$ + 25 percent technical $CaCl_2$ (85 percent pure) + 0.27 percent KNO_3 + 0.34 percent $Na_2Cr_2O_7$ (or $K_2Cr_2O_7$) + 0.25 percent Na_2CO_3 + 0.17 percent sea salt + 73.8 percent water (B216, Swiss Patent 251,327); $CaCl_2$ + Na_2SO_4 (B304); simultaneous introduction of 2.5 percent HCl and 10 percent quicklime based on cement weight (B334) or 2 percent HCl and 15 percent lime (B387); fine ground portland cement (5000 sq cm/g) with 2.5 or 3 percent $CaCl_2$ (B383); 120 gallons H_2O + 440 lb $CaCl_2$ + 13 lb $FeCl_3$ + 1.3 gallon $AlCl_3$ (32 percent solution) + 0.45 gallon HCl (37 percent) + 600 gm $BaCl_2$ (B435).

(2) Other inorganics. Many inorganic chemicals, in addition to $CaCl_2$, have been used to accelerate the set of portland cement. One of these mentioned very often is gypsum ($CaSO_2$) used by itself (B14, B31, B381, B421); in combinations which may produce gypsum in situ ($NaSO_4$ + $CaCl_2$) (B303); and in combinations with Na_2CO_3 and K_2CO_3 (B27). Other listed chemicals, grouped with their reference, are as follows: NaOH, KOH, $NaHCO_3$, $MgCl_2$, KCl, KBr, $KAl(SO_4)_2$ (B140); alkali metal hydroxides and carbonates, alkali earth chlorides, $AlCl_3$ (B241); $CaCl_2$, NaCl, NH_4Cl, $NaNO_2$, NaF, HCl, K_2CO_3, $Al_2(SO_4)_3$ (B384); sodium aluminate solution (33 percent) (B312); bleaching powder (B335); calcium oxychloride (B30, B87); Na_2SO_4, K_2SO_4, aluminum alums (B381); and fly ash (B382). Commercial liquid accelerators are Sika No. 2 and Sika No. 4A (B219), and Evoset 101T.S. (B307).

Three patents serve to illustrate use of some of these chemicals: Netherland Patent 86,937 (B342) - to accelerate cure, a dry powdered cement is admixed with soda ash (anhydrous Na_2CO_3), the effect is enhanced by

addition of an alkali metal bicarbonate, preferable in an amount of 40 percent based on the soda ash; Russian Patent 134,613 (B419) - a powder, produced by the fusion of bauxite with limestone and soda and ground to a specific surface area of 4500 sq cm/g, (product contains 70 percent sodium aluminate and ferrite and 30 percent dicalcium silicate), was added in the amount of 3 percent by weight of cement. The product set in 3 to 10 minutes without affecting the strength; and U. S. Patent 2,987,408 (B450) - the setting of portland cement plus finely ground blast furnace slag is accelerated by the incorporation of 0.1 to 5 percent of a finely ground, basic magnesium carbonate.

(3) Hydrated cements. Crystallization nuclei, prepared by pulverizing hydrated cement, are used for accelerating the hardening of concrete (B437, B447). French Patent 1,276,696 (B455) claims that the mechanical properties of a hydraulic cement are improved and its setting time is reduced by the addition of 2 to 3 percent by weight of powder of specially prepared preset cement.

(4) Organics. Some seven examples of organic accelerators or of organic combined with inorganic accelerators are given: all are patents.

(a) Netherland Patent 59,879 (B212). An aldehyde improves solidity. Action is improved by the use of metal chlorides, such as $CaCl_2$ (250 mg paraformaldehyde does not dissolve in 40 cc H_2O but is dissolved on addition of 20 gm $CaCl_2$ powder). One gram of mixture in 25 gm cement makes it bind within 30 minutes.

(b) U. S. Patent 2,435,594 (B219). A compound of residual solids of fermented sulfite liquor to which has been added a substitute benzoic acid or a salt

or ester thereof in concentrations of 0.01 to 0.6 percent and $CaCl_2$ 0.1 to 2.5 percent by weight of cement is added to a hydraulic cement. Accelerated rate of hardening as well as improved comopressive strength in early and late ages of concrete results.

(c) Japanese Patent 230 (B296). The agent is an emulsion comprising (in parts) 100 urea sulfate, 20 sulfonated oil, 100 whale oil, 3 poly(vinyl alcohol), and 1000 water. A cement mortar (1:3) molded with 60 percent H_2O and 3 percent emulsion hardened in 46 minutes and had a strength of 2630 psi after 3 days and a water penetration of 0.2 minutes under a pressure of 3 atm for 10 hours.

(d) U. S. Patent 2,827,385 (B372). A quick-setting cement consists essentially of from about 20 to 90 parts by weight of portland cement, from about 3 to 10 parts by weight of acrylate and from about 0.1 to 2 parts by weight of a catalyst selected from the group consisting of sodium thiosulfate and ammonium persulfate.

(e) German Patent 1,072,539 (B414). Approximately 0.1 to 5.0 percent, preferably 0.5 to 2.0 percent, $MgCO_3$ and a surface-active agent, such as triethanolamine, are added to reduce the setting time of cellular concrete.

(f) German Patent 1,073,928 (B427). The additives preferably consist of boiled, aqueous mixtures of rosin, linseed oil, and an emulsifier (soap). Thus 75 kg linseed oil was added to a mixture of 100 kg rosin and 75 kg soap. After boiling, 30 percent of this mixture was added to 70 percent water. The additive makes it possible to use 15 percent less water than usual, the hardening process is accelerated, and the frost resistance of the product is improved.

(g) U. S. Patent 2,948,699 (B432). Concrete is made to set rapidly by the incorporation of 0.05 to 2 percent of a polymer formed after the concrete is placed. This is accomplished by the addition of a water solution copolymerizable mixture of a monomeric alkyldieneacrylamide and an ethylenic comonomer, which react to form a water insoluble mass. For example, the mixture was 80 percent acrylamide and 4 percent N-N' methylene-diacylamide to which 8 percent ammonium persulfate and 8 percent sodium thiosulfate were added as catalysts. The mixture was dissolved in water and immediately added to the concrete mix. The rate of set depended on the quantity added. With a 2 percent addition of the mixture, setting took place in 15 minutes. High compressive strengths were obtained.

b. Organic accelerators. In the organic accelerators just described from the Highway Research Board's annotated bibliography, the use of a surface active agent such as triethanolamine was indicated. The use of organic bases, such as triethanolamine, have also been indicated as accelerators for high alumina cements.[D5] Another use of an organic accelerator, noted in one of the previously abstracted general studies (Section III.B.2.), and four uses, from Chemical Abstracts will be noted here.

(1) Calcium acrylate.[A1] Calcium acrylate is a monomeric water-soluble polyelectrolyte, which will polymerize in the presence of a catalyst to a water-insoluble polymer. A 3:1 soil:MiraMent Cement mixture required over 1 hour to set and the resultant sample was easily abraded. An addition of 5 weight percent calcium acrylate, on a soil basis, gave a mix having a set time of 10 minutes and the resultant material was abrasion resistant.

(2) Sodium methylsilicate, sodium aluminoethylsilicate and $CaCl_2$ [B45]. The addition of up to 1.5 percent $CaCl_2$ increased the compressive strength by 33 percent after 3 days and 5 to 6 percent after 180 days; 0.05 to 0.1 percent of sodium methylsilicate retarded the strength in initial stages but after 28 and 180 days, strengths were equivalent to $CaCl_2$ additions; simultaneous additions of sodium methylsilicate and $CaCl_2$ gave strength increases of 13 to 18 percent after 7 days; sodium aluminomethylsilicate (Si:Al = 1.9) additions gave initial low strengths but a 25 percent improvement in strength after 180 days.

(3) A polyhydric phenol-aldehyde condensation product (U. S. Patent 3,216,966). [B46] A mixture containing 36.3 cc of resorcinol and 36.1 cc of a 37 percent aqueous formaldehyde solution were mixed with 116.5 g of portland cement and 350 g of sand. The concrete sets after 15 minutes of stirring. After 1 week curing, the concrete had a density of 114 lb/cu ft and twice the tensile and compressive strength of concrete prepared without the additive.

(4) A polyhydric phenol-aldehyde condensation product (U. S. Patent 3,415,773). [B47] A mixture of 1 to 4 parts by weight calcium aluminate cement, 3 to 7 parts mineral aggregate per part of cement, 1 part resorcinol or phloroglucinol, 1.25 to 4 moles (per mole polyhydric phenol) paraformaldehyde, α-polyoxymethylene or β-polyoxymethylene and sufficient water to give a slurry of the desired consistency and for the hydration of the cement has a workable mixing time of 1/2 to 6 hours depending on the form of paraformaldehyde used. Example: 4 parts sand + 1 part mixture (60 weight percent calcium aluminate cement, 26.7 percent resorcinol, 13.3 percent paraformaldehyde) + water to

give 32 weight percent of the solids. The concrete set in 90 minutes, had a compressive strength of 1850 psi after 4 hours and of 4890 psi after 26 hours. Substituting polyoxymethylene for the paraformaldehyde and the set-up time increases with decreasing reactivity of the aldehyde. There is no significant increase in the working time when portland cement is substituted for the calcium aluminate cement.

(5) <u>Glucosaccharides (Belgium Patent 650,865).</u>[B48] Mixtures containing 0.05-0.25 percent glucosaccharides, 0.015 to 0.30 percent $CaCl_2$ and 0.01 to 0.05 percent triethanolamine (by weight of cement) are used in concretes and mortars of portland cement to increase the strength. (The glucosaccharides should consist of >45 percent polymers containing 3 to 10 glucose units and of <55 percent of polymers containing from 11 to 25 glucose units.) One recommended formulation increased the 7 day compressive strength from 2740 psi to 4310 psi and the 28 day strength from 4290 psi to 6070 psi.

c. <u>Inorganic accelerators.</u> In considering the use of these accelerators, one should be cautioned that in many cases, although they produce early set, the resultant concretes have very low early strengths.[A11]

(1) <u>In high alumina cements.</u>[D2,D5] In the study of high alumina cements, it was noted that many chemicals accelerated the set of these cements, similar to their effect in portland cements. Chemicals specifically mentioned were dilute solutions of sodium, potassium, and calcium hydroxides; dilute sulfuric acid, sodium or potassium carbonates and silicates; grains of prehydrated cement; and portland cement in high alumina cement and vice versa.

(2) <u>Calcium chloride.</u> In studying silico-phosphate cements, high early strength portland cement (Type III), with 0, 1, and 2 percent $CaCl_2$ admixture, was used as a control. It was observed that setting time without $CaCl_2$ was 4 1/2 hours; with $CaCl_2$ it was 1 1/2 hours.[B35] Allied Chemical Co. states that in standard portland cement mixes, 2 percent $CaCl_2$ can reduce initial set from about 3 hours to 1 hour and final set from about 6 hours to 2 hours.[B43] They also present an interesting table, Table XVI, showing the reduced time to obtain a compressive strength of 2000 psi using 2 percent $CaCl_2$. Duriez, in an addition to French Patent 1,248,475, claims that the addition of 0.5 percent KOH + 2 percent $CaCl_2$ to the mixing water increased the 2 to 7 day strength by 60 to 70 percent and the 28 day strength by 30 to 50 percent.[B50]

Dehydratine 80 (W. R. Grace) is basically a $CaCl_2$ solution.[A2]

(3) <u>Sika accelerators (Sika Chemical Corporation.</u>[B49]

(a) <u>Sigunit - accelerator for shotcrete (Gunite-Sika).</u> Sigunit is a $CaCl_2$ free accelerator. It is available as a slightly caustic white powder or as a green liquid. The powder is generally used at the rate of 2 to 8 lbs per sack of concrete; the liquid, at the rate of 1 to 3 gallons per sack. Used at the rate of 2 lb/sack, initial set occurs in 30 to 40 minutes, final set in 2 to 3 hours; at 4 lb/sack, initial set in 2 to 3 minutes, final set in 15 to 20 minutes; at 6 lb/sack, initial set is 3/4 to 1 1/2 minute, final set in 5 to 8 minutes.

TABLE XVI

TIME REQUIRED FOR VARIOUS CONCRETES
TO ATTAIN STRENGTHS OF 2,000 psi
(With and Without 2% $CaCl_2$)

Cement Type	Time in Days to a Compressive Strength of 2,000 psi	
	Plain Concrete	+ 2% $CaCl_2$
I. (Normal	4	1.7
II. (Moderate Heat)	5	2
III. (High Early Strength)	1	0.6
IV. (Low Heat)	9	4
V. (Sulfate Resisting)	12	6

In her summary to the Waterways Research Experimental Station literature survey for Concrete Technology Information Analysis Center (CTIAC-1), Clara F. Derrington states that Sigunit is composed primarily of Na_2CO_3 and silica gel. Bussone[B44] tested mortar cubes made using Sigunit and Na_2CO_3. Two and 3 gallons of Sigunit per bag of cement and 2, 4, and 6 percent of Na_2CO_3 by weight of cement were used. The cubes set in a few minutes but early strengths were low. Compressive strengths in 1 hour for the maximum amount of addition were 52 psi for Sigunit and 69 psi for Na_2CO_3.

(b) Sika No. 2 Quickset - for high pressure leakage. Sika No. 2 is a red liquid. Cement plugs made with Sika No. 2 bond tightly to concrete. Recommended concentrations are 2 parts of fresh cement to 1 part of Sika No. 2 by volume. Set occurs in 15 to 30 seconds.

(c) Sika Plug - quicksetting compound. Sika Plug is used to seal leaks and to make quick masonry repairs to floors, walls, and sidewalks. It is a grey, nonhygroscopic powder, ready to use. One part of water to 3 parts of Sika Plug sets in 3 to 5 minutes at 70°F.

(d) Sika No. 3 - accelerator for cement mortar. Sika No. 3 is a green liquid used to produce rapid hardening mortar for sealing joints in masonry or brick walls, or cracks in natural rock tunnels, retaining walls, etc. It is also used as an integral hardener for hard-wearing and rapid-hardening floors. At 70 to 80°F, stiff mortars produced by mixing a suitable cement with Sika No. 3 diluted with water in the ratios of 0, 1, 2, 3, and 5 had initial sets of 1/2 to 1 minute, 3 to 5 minutes, 45 minutes, 1 hour, and 2 hours, respectively.

(e) Sika No. 4 - grout Sika. Sika No. 4 is a caustic liquid to be diluted with water and mixed with cement for use in pressure grouting. The correct proportions

of Sika No. 4 varies from 1 pint to 2 quarts per sack of cement. Using 2 quarts of Sika No. 4 and 4 gallons of water to a bag of cement, stiffening takes place in 10 to 15 minutes and initial set in 1/2 hour at 60°F; 1 quart of Sika No. 4 and 4 1/4 gallons water, gives stiffening in 1/2 hour and initial set in 1 1/2 hours to 2 hours. If the temperature is increased to 80°F, set times are about halved; if the temperature is reduced to 40°F, set times are about doubled.

(f) Sika No. 4A Quickset - for moderate pressure leakage. Sika No. 4A is a clear liquid. Mixed with fresh portland cement it causes the mortar to set within 45 to 60 seconds. Setting time of mortar may be adjusted by diluting with up to 7 parts of water.

(g) In Fast-Fix cements.(A2) Sika No. 2 and Sika No. 4A were used as low temperature curing aids in Fast-Fix cements. It was noted that sodium silicate solutions performed equally as well as the Sika's at lower cost.

(4) Quick-Wotaito quick-hardening agent.(B56) The Nippon Cement Co., Kobe, Japan, manufactures a liquid quick-setting agent for cements. When mixed with 50 kg of cement: 30 liters of Quick-Wotaito + 0 liter of water gives a set time of 20 seconds to 2 minutes; 15 liter Quick-Wotaito + 15 liter water, a set time of 2 minutes to 20 minutes; 10 liter Quick-Wotaito + 20 liter water, a set time of 10 minutes to 50 minutes. No strength data were given.

7. Thermal Acceleration. Temperature is an important parameter in the rate of hydration and consequent setting time and strength development of all cements. This was

recognized by the charge that quick-setting cements for the rapid repair of bomb-damaged runways should be usable from about -5°F to 120°F. When the temperature is too low, water freezes and no hydration can take place. For normal outdoor placing of concrete, high temperatures are limited by the size of the energy source available and by the boiling temperature of water.

In the Highway Research Board bibliography[D4], it is stated that the best methods which can be used to produce an acceleration in strength gain in concrete are the use of rapid-hardening cement, the addition of chemical accelerators, retention of heat of hydration, and steam curing (B354). German Patent 806,345 (14 June 1951) refers to the acceleration of cement hardening by heating with alternating current and using accelerators such as alkali metal hydroxides and carbonates, alkaline earth chlorides or aluminum chloride (B241). (On line B-numbers refer to references in our reference D4).

A short heating in boiling water of concrete based on fine-grained cement increased the 1 day strength to 70 percent of the [illegible] day strength from 47 percent of the 28 day strength for ambient curing.[B41] In curing very fine portland cement concrete, the temperature was raised from 80°F to 180°F over a period of 1 hour and held for 2 hours, starting 1/2 hour, 2 hours, and 3 hours after mixing. Higher strengths were obtained for longer waits before the steam curing, but the early steaming gave much improvement over normal curing. Starting the steaming cycle after 1/2 hour set gave a 4 hour compressive strength of 5800 psi. Normal curing of the same material gave a strength of 3350 psi in 8 hours.[B37] For a certain cement formulation using Sika No. 4 accelerator, it was noted that the formulation set in 30 minutes at 60°F; when the temperature was raised 20°F, the set time was halved; when the temperature was reduced 20°F, the set time was doubled.

High alumina cements concretes were observed to be anomalous in their dependence of set times on temperature. Set time decreases from 34°F to a minimum at between 41 and 40°F, increases to a maximum at about 86°F, decreases very rapidly about 86°F so that high mix temperatures can cause genuine quick-set.[D2,D5] Strengths for high temperature cures are lower than for low temperature cures, however.

The silica-lime bond establishes itself at normal temperatures over 100 years or so. At elevated temperatures, it proceeds much faster. Pollet noticed many years ago in China that mixes of clay and lime had become very hard after centuries. He now has a pilot plant at Lille, France, in which he mixes clay and lime, heats in an autoclave to 400°F and gets strengths of 12,000 psi. He can also get these high strengths in conventional concrete by heating in an autoclave to 400°F.[E2]

One way to incude heat in a cement mix for curing at low ambient temperatures is to take advantage of heat developed in the base-acid reaction (portland cement + a weak acid such as HCl). With cement and aggregate at an ambient temperature of -15°F, and the mix liquid at 42°F, the resultant batch temperature would be about 24°F and the water would be frozen. When a 2 percent HCl solution was used for the mix liquid, the resultant slurry temperature was 37°F; 3 percent and 4 percent solutions gave slurry temperatures of 46°F and 52°F, respectively.[A2]

Fresh concrete on a new runway can be protected while curing from overnight below freezing temperatures with a 3 mm thick Dow Ethafoam polyethylene foam sheet. This sheet does not stick to concrete, leaves a smooth surface, and can be reused.[B51]

8. Miscellaneous.

a. Commercial quick-setting formulations. Several commercial fast-setting cements have been treated before under calcium sulfates (Paragraph III.C.2.). These were Hydro-Stone, IP Cement, Hydrocal White, Ultracal "30", and Fast-Fix. These will not be repeated here. No attempt has been made to gather a complete list of proprietary quick-setting cements.

(1) Regulated - Set Cement. This is a hydraulic cement whose setting time can be controlled from approximately 1 to 2 minutes to 30 minutes or so, with a correspondingly rapid development of strength. It was developed in the laboratories of the Portland Cement Association and, as of January 1970, is being produced by: (a) Lone Star Cement Corporation, Greenwich, Connecticut; (b) Huron Cement Division, National Gypsum Company, Alpena, Michigan; (c) Ideal Cement Company, Denver, Colorado; (d) General Portland Cement Company, Dallas, Texas; and (e) Louisville Cement Company, Speed, Indiana. For various amounts of "early-strength component," 1:2 mortars with a water:cement ratio of 0.4, have 1 hour strengths of about 0 psi to almost 2000 psi and 1 day strengths of about 2000 psi to over 4000 psi.[B57]

According to literature from Huron Cement Division, "Set Regulated Cement" is a modified portland cement with combinations of dead burned anhydrous calcium sulfate and hemihydrate calcium sulfate. These gypsums should be finely ground (>4000 sq cm/g).[B58] Mr. Bussone obtained maximum 1 hour compressive strength of 920 psi on 2 in. mortar cubes (using ASTM Method C109) for a water:cement ratio of 0.55.[B53]

(2) Darcrete fast-setting cement (Decar Chemical Company, Pittsburgh, Pennsylvania).[B55]

Mix 3 parts of Darcrete to 1 part of water (fresh or salt). Initial set takes place in 10 to 15 minutes; final set, 30 minutes later. Minimum compressive strength is 2200 psi in 24 hours; 6000 psi in 28 days.

(3) Exide Mari-Crete (Atlas Minerals & Chemicals Division, ESB, Inc., Mertztown, Pennsylvania).[B52] Mix for only 1 minute, 5 quarts of water per 50 lb bag of Mari-Crete. Set takes place in 6 minutes. Compressive strength is about 3000 psi in 24 hours.

(4) Siroc Grout (Diamond Alkali Company).[A13]

This is a two-component instant setting cement. Two slurries are made up: (a) calcium alumina + a Siroc chemical + water; (b) Type III portland cement + water. Lumps are formed almost as quickly as these two slurries are mixed together.

(5) "Quick-Set" Grout (Structural Clay Products Institute, McLean, Virginia).[B59] The basic formulation, by weight, for this grout is:

- 1 pt. cement mixture (52 percent Type I portland cement + 48 percent Lumnite high alumina cement)
- 0.8 pt. masonry sand
- 0.4 pt. water
- 0.1 to 0.3 pt. hydrated lime
- 150 ml dispersing agent per 100 lb of cement mixture (Calcium Lomer from Jacques Wolfe, Passaic, New Jersey)
- 15 ml air entraining agent per 100 lb of cement mixture (Ayrtrap from A. C. Horn Division of Sun Chemical)

Average compressive strength of 2 in. cubes were 200 psi in 10 minutes, 800 psi in 1 hour, 2000 psi in 7 days, and 2500 psi in 28 days.

(6) <u>Por-Roc (Hallemite Corp., Cleveland, Ohio).</u> In the laboratory, a mortar of 1 part cement, 3 parts sand had a compressive strength of 2000 psi in 30 minutes. In a field test, it set to a wet solid in less than 10 minutes and was load bearing in 20 minutes, but remained wet for at least a week.[A1] The material is high priced, being about $16.00/cwt on quantity discount prices.[A2]

(7) <u>Speed-Crete (Concrete Maintenance Products, Crystal Lake, Illinois).</u> Although quick setting in the laboratory, when premixed for field use (2 parts sand:1 part cement), the material did not become load bearing for 3 hours after mixing with water and pouring. It took 5 hours to set to hard, damp state. When specially mixed, the material still did not show gel properties for about 1 hour. Residual moisture in the brick sand used is believed to have caused the trouble.[A1] The material is priced at about $9.00/cwt. Water and shear in mixing are critical. A rubber-bladed mixer is required; shear forces to mix and pump are very high.[A2]

(8) <u>MiraMent (Sedden Co., Springfield, Ohio).</u> The best early compressive strength was obtained for a concrete composed of 50 parts MiraMent:25 parts sand:75 parts pea-gravel. This was 95 psi in 30 minutes. In a field test, mixed 1:1 with dirt, MiraMent set in the rain to support a man in 15 minutes and to a hard set in 30 minutes.[A1] When mixed with enough water to be pumpable, it is low strength - compressive strength of 500 psi in 30 minutes. Price is about $5.00/cwt in quantity.[A2]

(9) Florok Anchor Grout 4M28A (Vega Chemical, Newport Beach, California). The material is mixed using 32 parts water to 100 parts dry Florok. Maximum mixing time is 10 minutes; it can be mixed and poured in 30 seconds. Set time is 15 minutes; can be used in 30 minutes. Compressive strengths are 1800 psi in 20 minutes, 2500 psi in 30 minutes, 4700 psi in 1 hour, and 9800 psi in 24 hours.[B60] A testing laboratory report gives strengths of 4050 psi in 2 hours, 4625 psi in 1 day, 4125 psi in 2 days, 6200 in 3 days and 8325 psi in 7 days of air curing.[B61] Florok had mixing properties and general strength characteristics similar to Hydro-Stone. It was much higher priced at $13.00/cwt in large lots.

b. Russian formulations.[B54] The manufacture of rapid hardening and high strength portland cements is discussed: (1) raw mix preparation; (2) firing - quick firing to prevent the recrystallization of clinker minerals and the formation of large crystals, firing in a oxidizing atmosphere; (3) mineralogical composition of the clinker; (4) crystal structure and size of the clinker components - quality control of clinkers and cements, macrodefects, improvement of the hydraulicity; (5) particle size distribution of the cements; and (6) acceleration of cement hardening - main hydration products of most cements, addition of crystal hydrates, addition of highly reactive SiO_2, addition of freshly prepared highly reactive CaO.

D. MISCELLANEOUS CEMENT TECHNOLOGY

1. High Strength Concrete. Articles in this section do not necessarily pertain to high early strength concrete, but the information in the articles and the discussion of factors that contribute to high strength concrete should assist in

the development of a quick-set, high early strength material. Nasser[(D6)] has prepared a selected list of 17 references discussing methods for producing very high strength concretes. Nine of these references treat concrete in the 6000 through 14,000 psi compressive strength range and 8 treat concretes with strengths greater than 14,000 psi.

In June 1966, at the Fifth Congress of the Federation Internationale de la Precontrainte (FIP), meeting at Paris, France, a listing of our techniques for obtaining high strength concrete was prepared: increase cohesion between cement paste and aggregate; increase compaction; triaxial prestressing; and finely divided reinforcement.[(E1)] This list will be used to develop this section. On 14 April 1967, FIP, meeting at Venice, Italy, decided to concentrate on the first three of these approaches.[(E2)]

Exemplary of Japanese feelings along these lines: (1) Okada[(E8)] has prepared a review with 21 references on bonding materials (portland cements, alumina- or expanded cements, calcium silicates, and synthetic resins), aggregates, reinforcement with asbestos, steel wires or fibers, cement-to-paste mixing ratios, mixing and compacting methods for the production of high strength concretes (7000 to 14,000 psi) or super high strength concretes (>14,000 psi); (2) Uchikawa[(E9)] has preapred a review with 22 references on the chemistry of cement clinkers and hydration, properties of cement pastes, factors influencing strengths of cement pastes, coagulation, hardening processes and strengthening mechanisms of cement mixtures, and compression or bending strength of mortars and concretes.

a. <u>By improvement of cement-aggregate bond.</u> It is the adhesion between cement matrix and aggregate which fails with conventional concrete in the range of 9000 to 10,000

psi.[E2] Three methods used to improve this bond will be discussed here.

(1) Cementitious aggregates.[E1,E2,E4] Some natural limestones and granites have cementitious properties. Portland cement clinker, using overburnt vitrified clinker, in a mix with a water-cement ratio of 0.3 has given strengths of 17,000 psi in 90 days. Some of the harder slags are being investigated. Aluminous cement clinker, the most promising, has produced concrete in the 13,000 to 15,000 psi range.

U. S. Patent 3,389,003[E5] claims the use of an admixture of pozzolan, foamed basalt powder, quartz flour, sand, or volcanic aggregate, first formed with water and Na_3PO_4 into a hard block and then pulverized, to increase the compressive strength of the resulting concrete.

(2) Silica-lime bond.[E1,E2,E4] The silica-lime bond establishes itself at normal temperatures over a time period of a hundred years or so. By compacting the wet paste by a pressure of 14,000 psi and heating to 200°C silica-lime bonds as high as 28,000 psi have been produced. Free silica and free lime are normally present in portland cement and strengths as high as 12,000 psi have been obtained by heating to 200°C in an autoclave.

(3) Synthetic-resin concretes.[E1,E2,E4] Synthetic resins have good bond strength to stone (epoxy resins are of the order of 2100 psi) so resins have been used: as a matrix; to precoat the aggregate before use in concrete; as an admixture with the mix water; and to inject into a cured concrete mass.

(a) Resins as the matrix. The "General Studies" section of this report (Section III.B.2.) gives information on the use of epoxy resins, polyester and vinylester resins, and phenol- and ureaformaldehyde resins as soil and aggregate binders.[A1,A2,A11] Epoxy resin as a matrix gives a very viscous mix; large quantities of expensive resin are required; and the resulting solid, though of a strength well above 14,000 psi, has a low modulus of elasticity.[E1]

(b) Precoating the aggregate.[E1] Mixing aggregate, precoated with epoxy resin, with cement paste has increased 7 day strength by a factor between 2 and 2.5. Compressive strength was still low, about 4800 psi, but in tensile tests the coated aggregate was split through whereas uncoated aggregate was pulled out of the matrix.

(c) Plastic admixtures. Under the section on "Accelerating Admixtures, Organic Accelerators" (Section III.C.6.b.) several cases were mentioned of plastics both accelerating set and increasing the strength. Some materials listed were a polyhydric pheno-aldehyde condensation product formed in situ during curing of concrete[B46,B47] and glucosaccharides.[B48] Reference B432 of the Highway Research Board's bibliography[D4] also states that addition of a polymer caused rapid setting and high compressive strength.

(d) Polymer impregnated concrete. Pollet has injected with epoxy an artificial aggregate of cubit shape formed of highly compacted cement. Four percent resin by weight of total mass was needed.[E1] Atlas Minerals and Chemical Division, ESB, Inc., make a "Concrete Polymer" said to be four times stronger than ordinary concrete, highly resistant to abrasion and freeze-thaw damage, almost 100 percent resistant to corrosion, and resistant to the

effects of brine and distilled water heated as high as 290°F.[E3] The material is made by placing the concrete in a vacuum and then soaking in a liquid monomer such as methyl methacrylate. Curing is catalyzed by exposure to radiation (Cobalt 60), radiation plus heat, or by heat and organic catalysts. Penetration of the plastic can be controlled; complete penetration increases the weight by about 7 percent.

b. <u>By better compaction.</u>[E1,E2] Compaction of the cement particles would increase the density of the tensile bond and thus increase cohesion and internal friction. The following methods of compaction have produced high strength concrete.

(1) <u>Compression of cement paste.</u> Several workers, since the 1930's, have produced strengths of the order of 21,000 psi by direct application of pressure to the cement paste. One (Abrams) is said to have produced a cylinder of 40,000 psi by this method. Relative low pressures (7 psi) plus autoclaving have given strengths of about 15,000 psi; pressures of 60 psi have given strengths of 20,000 psi.

(2) <u>Compression by vibration.</u> There is a relationship between the frequency of vibration and the size of the particle compacted. Present vibration frequencies compact only the coarse aggregate. Ultrasonic frequencies could presumably be employed to compact the sand and even the cement particles. Maus in Germany has obtained strengths of 20,000 psi with ultrasonic frequencies on very small samples. In the Soviet Union, very high frequencies have been applied to grout mixes, resulting in high strengths.

(3) Grading of cement. It has been suggested that the variations in strength which exist between apparently identical cements are explicable by a grading of particle size which, fortuitously, gives better compaction. (Under raw mix preparation, the use of common mesh sizes was mentioned for obtaining superstrength cements.[B54])

c. By triaxial prestressing.[E1,E2,E4] A restraint of stress laterally applied during loading will give an increase in the longitudinal strength of some four-fold. Harris in England has taken conventional concrete of 10,000 psi and by providing a high degree of spiral wrapping has increased the longitudinal stress to 50,000 psi. By hydraulically applying a transverse stress of about 26,000 psi, McHenry and Balmer recorded a crushing strength of 82,000 psi.

d. By finely divided reinforcement.[E1,E2,E4] Wires, nails, steel wool, high tensile fibers, etc., have been used to reinforce concrete. Only asbestos cement seems to have succeeded commercially and little information is available concerning its compressive strength. Mathers refers to strengths of over 18,000 psi obtained in 1910, using nails. Strengths of 30,000 psi have been obtained in small samples with cement and nails.

Nylon fibers (3/4 in. long, 15 denier) were used to reinforce MiraMent cement.[A1] Flexural strengths were 177 psi for 0 weight percent fibers; 190 psi for 1 percent; 191 psi for 2 percent; and 192 psi for 4 percent. The stress-strain curves were noted to take on a plastic characteristic when fibers are used. Samples with 2 and 4 percent fibers cracked at the yield point but remained intact and, upon removal of the load, returned to their original shape.

Fibers of fiber glass 1/8 in. long were blended with Fast-Fix 1 cement at weight percentages up to about 3.(A2) Up to 2 percent could be added without greatly affecting mixing operations; higher percentages required increased mixing times and created difficulty in achieving homogeneous mixes. Flexural strengths were increased from about 500 psi to 600 psi for 40 percent mix water and from about 750 psi to 850 psi for 32 percent mix water - comparing 3 percent to 0 percent fiber. Nylon and fiber glass were also tested in the form of loose fiber, mattings, cloth and roving. In general, the cloth, roving, and matting were of little benefit, due to the fact that the cement slurry did not completely penetrate them. In tests to determine the types of reinforcement that could be penetrated, the most promising material was 6 in. lengths of loose fiber glass. This material was placed in flexural molds and a 35 percent mix water slurry poured over it. When tested 1 hour after pour time, flexural strength was 1060 psi. Unreinforced flexural strength would have been about 700 psi.

Pashchenko, et al,(E11) studied the adhesion between cement paste and glass fiber by measuring the force required to peel a glass fabric (180° peel) from the surface of cement moldings. Alkaline and non-alkaline glasses were used. Cements used as adhesives were aluminous, gypsum-aluminous, pozzolanic, portland cement, and blast furnace portland cement. Adhesion decreased for an increase in the water-cement ratio. Adhesion was greater between non-alkaline glass and cement paste than for alkaline glass. The greatest adhesion was for aluminous cement and non-alkaline glass.

e. By improvement of condition at rupture.(E1) Understanding the mechanics of fracture can suggest means which substantially postpone the moment of rupture and thus increase the strength. The "lenticulated concrete" of Duriez seems to fall into this category. Since concrete fails by the formation of cracks, if the propagation of cracks were inhibited, the strength would be higher. Duriez has done this by replacing the fine aggregate by 2 to 3 percent by weight of the cement of polyethylene or polystyrene "confetti," or "lenticules," 0.025 mm thick and 3 to 4 mm in diameter. These appear to act as "crack stoppers" without necessitating extra water for workability, as would an ordinary sand. Three cubes made in this manner gave an average strength of 15,000 psi at 90 days. (Several of the previously noted techniques tend to also reduce crack propagation: finely divided reinforcement, triaxial prestressing, synthetic-resin concretes.)

2. High Strength Concrete - Special Techniques.(E12) The relative effectiveness of a number of special techniques and admixtures in producing high compressive strength concretes was explored.

a. Water reducing agent. Use of lignosulfonic acid was found to be the most effective means of increasing strength levels in low water-cement ratio mixes. The increased strength afforded by the water reducing agent appeared to be greater than would be expected from the amount of water reduction produced. Strength at 7, 28, and 90 days were improved by about 2000 psi (6000 to 8000 psi; 7000 to 9000 psi, and 8000 to 10,000 psi, respectively).

b. Revibration and high speed slurry mixing. All specimens were vibrated when cast. Revibrated specimens were vibrated again for a period of 9 minutes, 3 hours after they had been molded. In all but one case revibration produced strength increases of between 1.2 to 20.8 percent. High speed slurry mixing produced strength increases from 1.6 to 19.6 percent.

c. Fly ash addition. A 10 percent replacement of cement with fly ash produced strength increases between 10.3 to 17.9 percent for water-cement ratios of 0.31 and 0.35. For a water-cement ratio of 0.39, there was little difference from the standard mix.

d. Seeding with finely ground, fully hydrated portland cement. This technique appears to hold the least promise of those tried. At a water-cement ratio of 0.31, the seeded mixes were from 3.5 to 11.4 percent lower than the standards at all ages; at a w/c of 0.35, the seeded mixes were from 5.0 to 11.2 percent higher than the standards; at a w/c of 0.39, there were practically no differences between the standards and the seeded mixes.

e. Compaction. When working in the low water-cement ratio ranges, the problem of compaction is encountered and it would seem that the strength available will depend to quite an extent on the degree of compaction that it is possible to achieve. For water-cement ratios of 0.31, 0.35, and 0.39, 28 day strengths were 7125 psi, 6888 psi, and 8120 psi, respectively, because air void contents were 5.4, 1.8, and 0.5 percent, respectively.

3. <u>High Strength, High Density Concrete.</u> High strength, high density concrete has been made with normal portland cement and iron ores as aggregate (1/2 or 1 1/2 in.). For a cement content of 7.7 to 10.3 bags/cu yd and water-cement ratio of 0.30 to 0.35, the density of the concrete was 230 ±5 lb/cu ft and compressive strengths were 7600 to 9400 psi in 7 days and 10,000 to 12,000 psi in 3 months.[E6]

4. <u>Silicate Concrete.</u>[D7] Tarasov claims that silicate concrete slabs of considerable strength and frost resistance can be obtained under industrial conditions from lime and sand. Construction properties are close to those of portland cement concrete; it is 10 to 25 percent cheaper and white in color. Unit weight is 100 to 112 lb/cu ft; compressive strengths are 6800 to 8700 psi, tensile strengths (under flexure) are 850 to 1100 psi.

5. <u>Cementitious Ceramic Materials.</u>[E10] Cementitious, or "air setting" ceramic materials develop their final properties at temperatures seldom exceeding 500°F. They are useful to about 4000°F. They can be used as coatings, as seals and as potting compounds. Another reaction type cement is magnesium oxychloride, which is a weather sensitive material. Some typical commercial cements follow.

a. <u>Astroceram (American Thermocatalytic Corporation, Mineaola, New York).</u> There are two types with melting temperatures of 4400°F and 4285°F. They have a coefficient of thermal expansion of 4.11×10^{-6} in./in./°F, shrinkage of 1 to 4 percent, and density of about 175 lb/cu ft. The more refractory cement (m.p. 4400°F) must be heated to 1100°F to attain proper bonding; the other must be heated to 2200°F.

b. <u>Sauereisen Cements (Sauereisen Cements Company, Pittsburgh, Pennsylvania).</u> These materials are a series of cements ranging from refractory to acid resistant to electrical-insulative. Oxides (especially silica and alumina), kyanate, and silicates are included in their composition. Bonding is believed to be due to alkali silicate reaction. Such properties as hardness, adherence, abrasion resistance, and thermal shock resistance vary greatly depending upon specific applications. These cements are true air-setting and require no heat for bonding. Set time can be varied by changing the proportions of the constituents.

c. <u>Zircoa-Cast (Zirconium Corporation of America, Solon, Ohio).</u> This is a castable zirconium oxide material which hardens by hydraulic action. It has withstood short-term exposure to temperatures in excess of 5000°F and cycling or steady-state temperatures to 4600°F. Shrinkage is less than 1 percent when heated to the bonding temperature of 800°F. The density of the bonded material is about 260 lb/cu ft. Spall and thermal shock resistance are acceptable, but abrasion resistance and adherence to metal substrates are poor.

d. <u>Phosphate-bonded foamed aluminum.</u> A lightweight phosphate bonded alumina material was formed by means of an acid reaction with aluminum powder in the presence of a foam stabilizer. When properly dried and cured, the material had a shrinkage of less than 1 percent, a density of 118 lb/cu ft, thermal conductivity of 6.6 Btu in./hr sq ft °F, and a flexural strength of 700 psi. This material can be used to a temperature of about 3100°F. A zirconia body of the same type could be formed which should permit operation at temperatures above 4000°F.

E. ROADS, RUNWAYS, COMPACTED AREAS, SOIL STABILIZATION

We have two main aims in including this section: (1) to present some of the requirements for runways and related surfaces in order to indicate what "patches" of high early strength cement concrete must endure, and (2) to present some miscellaneous information on runways and related surfaces in order to indicate some continuing needs, where better answers are needed. No attempt has been made to make this section complete; only a small fraction of the known available literature was ordered and reviewed.

1. Basis of Runway Designs.

a. Unprepared and semi-prepared airfields. In war, airplanes may have to operate from unprepared landing areas. AGARDograph 45[C2] surveys this eventuality. In order to know which unprepared airfields are usable for different type of aircraft, it is necessary to classify these fields. Atmospheric and terrain parameters are used for this classification. Atmospheric parameters are air temperature and its changes in the course of the day and year, wind velocity and direction, rain, fog, and haze. Terrain parameters are area elevation, dimensions (length, width), area slope (in both directions), undulation, surface roughness, approach and climb-out obstacles, and soils. The nature of the soil and its suitability for flight operations depends highly upon the weather. The possibility of snow and ice upon the airfields must be taken into account.

Essentially the following methods were considered in preparing semi-prepared runways in Germany: cement-soil stabilization, bituminous sand course, bituminous soil stabilization by special granulometry (e.g., clay and

gravel mixes); and surfacing by metal sheets, grates and mats, by concrete grates, and by wooden elements (timber mats, wood paving).

Aircraft must have proper landing gear. Their suitability, especially on soft ground, depends on the specific ground load (wheel dimensions, tire pressure) and on the arrangement of the wheels (e.g., twin-wheel units). The design of the landing gear and the nature of the soil also influence the rolling resistance and the braking effect. Test results are presented for these topics, as well as for several landing gears specially designed for aircraft operating from unprepared areas. Maximum recommended tire pressures for various landing surfaces are: aircraft carrier deck - above 200 psi; large military airfield, properly maintained - 200 psi; large civil airfield, properly maintained - 120 psi; small tarmac runway, good foundation - 70 to 90 psi; small tarmac runway, poor foundation - 50 to 70 psi; temporary metal runway - 50 to 70 psi; hard grass, depending on soil - 45 to 60 psi; wet, boggy grass - 30 to 45 psi; hard, desert sand - 40 to 60 psi; soft, loose, desert sand - 25 to 35 psi.

Earlier in this survey, (Section III.B.3.a.), the application of a filled, chlorinated polyester resin (Rapid Site) over bare ground or turf to form a surface for the takeoff and landing of jet VTOL aircraft was discussed. This material withstood the heat of the jet blast and protected the aircraft from flying object and debris damage.[A7,A8]

b. <u>Short Airfield for Tactical Support (SATS).</u>[C18] SATS installations are designed for launch, recover, and service conventional military aircraft and helicopters. SATS airfields require the use of expedient surfacing

materials, such as landing mats, soil stabilizers, and dust palliatives, rather than conventional asphalt and portland cement concrete. The greatest problem encountered using mats is a soil pumping action which can take place beneath them. Special steps must be taken to stabilize and protect the base course to resist this pumping action.

In evaluating and preparing the subgrade one should try for a CBR of 10; 6 is acceptable; 4 is the design limit for AM-2 matting. Portland cement and bituminous materials such as asphalt and tar, are the most readily available commercial materials suitable for use as mechanical soil stabilizing agents.

c. Rigid pavements for military airfields.[A2,C16] The U. S. Army Corps of Engineers was assigned responsibility for the design and construction of military airfield pavements in 1940. Hutchinson[C16] summarizes some 26 years of experience and research, and includes a good bibliography. Subject headings are as follows: basic loading and stress conditions; determination of critical stresses - by equation, by influence chart, by model studies; modulus of soil reaction - determination by volumetric displacement, determination by field plate loading test; determination of concrete strength; traffic loading; coverages; traffic areas; design factor; load transfer; equivalent single wheel load; failure concept; frost considerations; drainage considerations; development of rigid pavement chart; methods for reinforced rigid pavement design; design of overlays for strengthening existing rigid pavements; and development of design method for prestressing concrete pavements.

There are three basic conditions of loading a runway: interior loading, corner loading, and edge loading. The load is assumed to be applied uniformly over an area

equal in size and shape to the footprint of the aircraft tire on the pavement. Edge loading, tire footprint tangent to the edge of the pavement, is assumed to be the most critical. Dr. H. M. Westergaard developed an equation for the determination of critical stress due to edge loading. This equation is shown on the following page.

This Westergaard equation is for a wheel footprint tangent to the edge of a pavement. It is not so good for computation of edge stresses under multiple-wheel gear loadings where influence charts, which are graphical solutions to the equation, are normally used. Pickett and Ray[C20] developed 8 influence charts presenting solutions for four cases: interior loading, assuming a liquid subgrade; interior loading, assuming an elastic solid subgrade; edge loading, assuming a liquid subgrade; and one-half the radius of relative stiffness from an edge, assuming a liquid subgrade. Later, Pickett, et al,[C21] developed an additional 16 influence charts for the determination of deflection, moment and reactive pressure under interior, near edge, and near center loadings of slabs for liquid, elastic solid, and elastic layer subgrades.

$$\sigma_e = \frac{12(1+\mu)P}{\pi(3+\mu)h^2}\left[K + 0.8659\,\frac{\mu}{4}\,B_1 + \frac{1-\mu}{4}\,S + B_2\,\frac{\bar{y}}{l}\right]$$

σ_e = maximum edge stress, psi

P = wheel load, lbs

h = slab thickness, in.

μ = Poisson's ratio of concrete

$\bar{y}$ = distance from edge of slab to center of gravity of the loaded areas (contact area) in.

B_1, B_2 = dimensionless constants dependent upon μ
$B_1 = 0.9627$; $B_2 = 0.4131$ for $\mu = 0.20$

l = radius of relative stiffness, in., and is a measure of the stiffness of the slab relative to that of the subgrade. l is computed from the formula:

$$l = \left[\frac{Eh^3}{12(1-\mu^2)K}\right]^{1/4}$$

K = modulus of soil reaction, psi/in.

E = modulus of elasticity of concrete, psi

K = an area coefficient

S = an area coefficient

For an elliptical footprint, where

a = semi-major axis, in.

b = semi-minor axis, in.

$$K = \log \frac{2l}{a+b} + \frac{a-b}{2(a+b)}$$

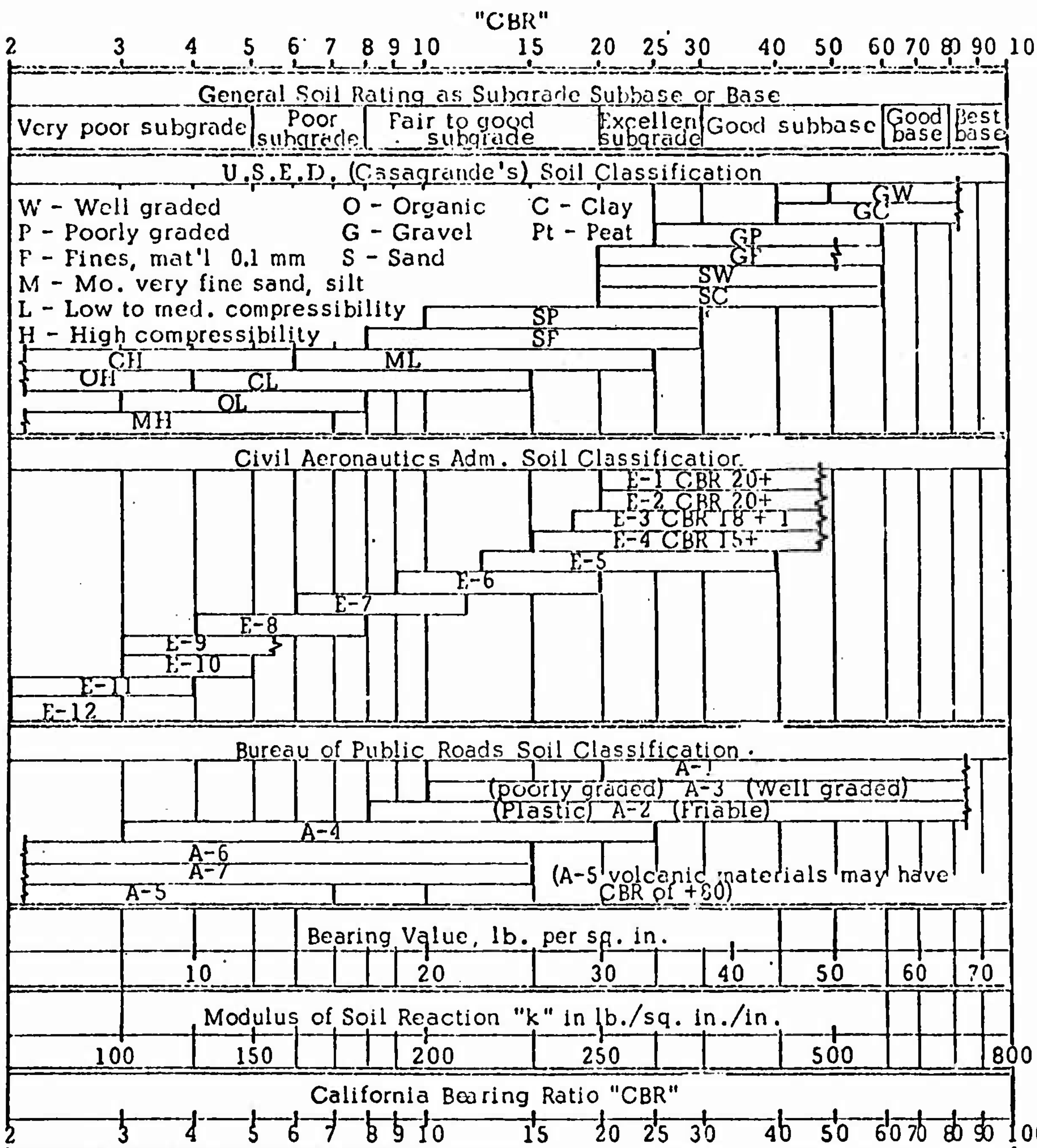
$$S = \frac{2\,ab}{(a+b)^2} - \frac{a-b}{a+b}$$

Critical stress in a concrete slab occurs due to bending of the slab under wheel loading. The Corps of Engineers has adopted the flexural strength of the concrete as being the most representative property for design purposes. Flexural strength is determined on 6 in. x 6 in. x 18 in. beams, using third point loading. Tests are made at 7, 28, and 90 days after casting. The strength at 90 days is used, in most cases, to determine the required slab thickness. Other tests which are made on concrete: static and dynamic modulus of elasticity, Poisson's ratio - freeze-thaw durability, air entraining admixture determination, alkali reactivity tests on the aggregate, deleterious material content in the aggregate, tests of the cement for specification compliance, slump, etc.

The Westergaard equation relates stress in the slab to the "radius of relative stiffness" (l), a measure of the stiffness of the slab relative to that of the subgrade. The subgrade reaction, "modulus of soil reaction" (k), is approximated in various ways. Table XVII relates it to CBR, to various type soils, and to soil classification systems. One measurement technique is to load the soil using a 30 in. diameter steel or aluminum plate of specified stiffness. "k" is the load in psi divided by the soil depression in inches at that load (linear portion of stress-deflection curve made to pass through the origin; sometimes taken as $\frac{\text{load = 10 psi}}{\text{deflection at 10 psi load, in.}}$. The worse possible value of k should be used. This would normally be for a saturated subgrade. For soils with high k values, the predicted required slab thicknesses can be reduced: by 4.6 percent for a k value of 300 psi/in.; by 10.6 percent for a k of 400; by 19.2 percent for a k of 500.

TABLE XVII

INTERRELATIONSHIPS OF SOIL CLASSIFICATIONS, CALIFORNIA BEARING RATIO, BEARING VALUES AND "k" VALUES



All interrelationships are very approx. Actual tests are required to determine "CBR" "k" etc.

From: Design of Concrete Airport Pavement, Portland Cement Assoc., Page 8, 1955.

Frost susceptible soils are considered to be any soil containing 3 percent or more by weight of grains finer than 0.02 mm in diameter. Detrimental effects are manifested by excessive heaving, often non-uniform, and by loss of subgrade strength when the frozen soils are thawing.

Offhand, one would imagine that landing loads would represent the most critical condition of slab loading. Actually, normal landings apply only to 40 to 60 percent of the static load to the slab; the most severe landings apply from 150 to 200 percent of the static load and these are rare. Also, since deflection of the subgrade is time-dependent, a quickly applied, above normal landing load is less effective in overloading the slab. Thus a static or slow moving load is taken to represent the most critical condition of loading and is used for design.

Test tracks from the study of slow moving, repetitive loadings were also used to evaluate slab sizes; joint designs; base courses; temperature, moisture and weather effects; compaction requirements; steel reinforcement in the concrete; rigid and non-rigid overlays of existing rigid pavements; prestressed concrete pavements; traffic patterns; different gear configurations and loadings; construction techniques; concreting materials; and testing techniques.

d. Prestressed concrete pavement taxiway.[C8] The first prestressed concrete pavement to be constructed in a military airfield in the United States was that incorporated in the reconstruction of Taxiway T-3 at Biggs AFB, Texas. This taxiway was reconstructed to support the B-52 bomber. The pavement was 75 ft wide, 1500 ft long, and 9 in. thick. It was prestressed by the post-tensioning method, using button headed 1/4 in. diameter high tensile strength wires.

Each longitudinal tendon consisted of a group of 12 such wires placed within a flexible steel tube. The transverse tendon consisted of six such wires placed in rigid steel tubing. The design was such that the final prestress was to be 350 psi in the longitudinal direction and 175 psi in the transverse direction. The subgrade support for this design required a modulus (k) of 200 psi/in. The 1500 ft pavement consisted of three 500 ft slabs of prestressed pavement connected with short reinforced concrete sections. Adjoining one end of the 9 in. thick prestressed pavement was a 1500 ft section of 19 in. thick reinforced pavement. The remainder of Taxiway T-3 was made of 24 in. thick plain concrete pavement. Thus prestressing, according to these designs, required 52 percent less concrete than was necessary for reinforced concrete runways and 62 percent less concrete than was needed for an ordinary concrete runway. Construction was completed in July 1959. The pavements were designed to carry a stress, due to the wheel load, of 750 psi. Concrete mix details, pouring details, consolidation of the concrete by vibration, etc., are given, but there is no data on subsequent service.

e. Snow and ice runways. A large amount of literature relative to the preparation of snow and ice runways has been developed within the past five years. Four of these articles have been referenced. Snow runways capable of supporting a C-130 aircraft on wheels can be constructed with suitable equipment but are reliable only during comparatively low temperatures (below 5°F). The feasibility of supporting a C-121 on wheels on these type runways would appear to be marginal. The annual sea ice at McMurdo Sound is capable of supporting these cargo type aircraft. (A C-130E aircraft has a gross weight of 125,000 lb and tire

pressure of 85 psi; a C-121C aircraft has a gross weight of 130,000 lb and tire pressure of 120 psi.) Some type of snow runway surface strengthening seems to be necessary for the C-121, unless the temperature is below 5°F for several days. A landing mat or additives may be considered for this strengthening. The occurrence of above freezing temperatures at McMurdo during the Antarctic summer months is the most serious and detrimental factor as far as dependability of reliable snow runway is concerned.[C11]

Previous work had shown that white urethane foam granules mixed with snow or ice chips would protect ice and snow surfaces against thaw conditions. Research was subsequently conducted by Goodyear Aerospace Corporation to develop needed improvements in the areas of wind resistance and trafficability.[C15] Satisfactory insulating layers were made from sawdust and snow, 50/50 mixture of foam granules and snow, and 67/33 mixtures of foam granules and snow. Density of the foam was 3.5 lb/cu ft.

Stehle[C22] summarizes that, for protection of ice areas against ablation, chipped ice is easiest to produce and the most economical to use, but gravel, sawdust, urethane foam, concrete planking, insulated metal planking, timber decking, and snow may be more effective and economical for specific conditions.

2. Airport Pavement Requirements. Early airport design and construction was a carry-over of highway practice until the late 1940's. The only consideration of the designer, up to this time, was the effect of the aircraft weight on the pavement. He designed to meet these requirements. With the increased use of military jet aircraft in the 1950's, the following factors were introduced into airport design considerations: jet blast, jet fuel spillage; foreign object

damage; high pressure tires; higher aircraft speeds; center line lighting; high-speed turnouts; multiple-wheel gears; channelized traffic; aircraft porpoising; fuel-resistant joint sealers, and others.(C6)

The DC-8-55 aircraft, when applied to the runways at John F. Kennedy Airport, is estimated to produce a working stress of 405 psi, using the Westergaard analysis. This assumes a concrete thickness of 12 in., a subgrade modulus of 300, and 95 percent of the total weight of 325,000 lb on the main gear. (Later models of the DC-8 (-61, -62, -63) have maximum take-off weights from 325,000 to 350,000 lb and computed stress development in the concrete of 418 to 443 psi.) All versions of the DC-8 have a twin tandem main landing gear with four wheels. Each wheel mounts a 44 x 16 tire which, when inflated to 32 percent reflection criterion, has a contact area of 209 sq in. Test values for concrete aged 28 days usually average at least 700 psi. Using the maximum applied stress in parenthesis above, of 443 psi, a strength of 700 psi would give a safety factor of 1.6. With further aging, the strength of the concrete and the resultant safety factor are increased.(C4)

3. Airfield Pavement Evaluation. To evaluate the performance and service life of an airfield pavement properly, some type of condition survey is necessary. Such factors as subgrade soil strength, thickness and type of subbase, frost, drainage, pavement thickness and concrete strength, jointing design, aircraft traffic, climatic conditions, and maintenance history may be evaluated depending on the type of condition survey that is undertaken. Pavement evaluation procedures usually are the reverse of the pavement design procedures; i.e., in evaluation, the pavement thickness and strength of the subbase and subgrade are known or can be

determined. From these data, conclusions are drawn about allowable aircraft loadings that can safely use the pavement.(C6)

Brown(C5) describes five airfield evaluation procedures in use in the United States and abroad as of 1964: the U. S. Army Corps of Engineers; U. S. Navy Bureau of Yards and Docks; U. S. Federal Aviation Agency; United Kingdom Ministry of Aviation; and the Canadian Department of Transport. The U. S. Army Corps of Engineers evaluation procedures involved: (1) General information - construction and maintenance history, complete traffic history, summary of current traffic, rainfall and temperature data, examination of drainage features, geologic and soil descriptions. (2) Surface conditions - visual inspection and appraisal of condition, photographs of typical defects, complete mapping of cracks and defects. (3) Location, number, and type of tests - pilot holes at approximately 500 ft for thickness and classification tests. (Flexible Pavement) test pits in selected locations representative of pavement cross sections and in weak areas for materials tests and in-place CBR tests on each full 6 in. of base, subbase, and subgrade (12 to 20 test pits for one runway, taxiway, and apron). (Concrete Pavement) 5 or 6 test pits at selected locations for beam samples, and 30 in. plate load tests on base course. (4) Tests of pavement materials - (Concrete) modulus of rupture, compressive strength, tensile splitting, thickness. (Bituminous Layers) thickness, density, bitumine content, aggregate gradation, stability and flow of cores, stability and flow of recompacted sample, voids, properties of extracted bitumine. (Base, Subbase, and Subgrade Materials) thickness, in-place density, moisture content, gradation, classification tests, specific gravity, laboratory compaction,

laboratory CBR, and (Soil Profile and Water Table). (5) Method for determining load capacity - (Flexible Pavement) compute from measured thickness and subgrade CBR using CBR design method. (Concrete Pavement) compute from measured thickness, strength and modulus of subgrade reaction using modified Westergaard analysis for edge loading. (6) Method of presenting load ratings - allowable gross aircraft loadings for nine landing gear configurations varying from single wheel type to twin-twin bicycle type are given. Each pavement item is rated for four operational categories (capacity, full, minimum, and emergency). The primary runway pavement is divided into a, b and c traffic areas characteristic of anticipated traffic requirements for purposes of rating.

Reports on evaluation of three U. S. Navy airfields(C10,C12,C17) show that use is made of surface plate loading tests on asphaltic concrete pavements; both asphaltic concrete and portland cement concrete pavements are sampled and portions are removed for testing; plate loading tests are made on base, subbase, and subgrade.

Table XVIII lists some of the tests and test methods used; all of which are specified in NAVDOCKS DM-21. For USNAF China Lake, California(C10), allowable gross aircraft loads for Runway 3-21, for various wheel gears using a tire pressure of 150 psi, show the spreading load effect of various complex gears: single wheel gear - 206,000 lb; dual wheel gear - 268,000 lb; single tandem gear - 342,000 lb; dual tandem gear - 402,000 lb.

4. Surface Repair (Patching). Previous sections have discussed the use of various cements (quick-setting and normal) in repairing roads and runways. The use of plastic latexes to improve properties such as adhesion and weather resistance has also been discussed. The airfield pavement

TABLE XVIII

AIRFIELD PAVEMENT EVALUATION

STANDARD TEST METHODS USED

Property	Test Method
Portland Cement Concrete - Cores and Beams from Pavement:	
Thickness	
Examine for deficiencies	
Tensile splitting test	ASTM C496-64T
Flexural strength (modulus of rupture)	ASTM C42-61
Ashpaltic Concrete:	
Marshall stability and flow	ASTM D1559-60T
Hot extraction	ASTM D762-49
Penetration	ASTM D5-61
Ductility	ASTM D113-44
Subsurface Materials:	
Gradation of aggregates	ASTM C136-61T
Specific gravity of aggregates	ASTM D854-58
Plastic limit and plasticity index of soils	ASTM D424-59
Liquid limit of soils	ASTM D423-61
Moisture-density of relationship of soils	ASTM D1557-61T
California Bearing Ratio	Corps of Engineers EM-1110-45-302
Compressive strength of soil-cement cylinder	ASTM D1633-59T

evaluation of Lowe and Chamberlain[C17] points out that problems continue to exist: portland cement concrete repair patches are not holding; epoxy asphaltic concrete shows a general cracked condition; slurry seal coat has been removed due to concentrated jet blast and there, also, is jet blast damage on connecting taxiways.

A pamphlet by the Portland Cement Association[C1] presents some rules for placing concrete patches: a thin layer of warm concrete should not be placed on cold hardened concrete; special precautions need to be taken during hot or cold weather; in finishing concrete, patches should not have feathered edges; edges should be at least 1 in. deep.

The New Jersey Department of Transportation surveyed the other states and toll-road authorities relative to their "Pavement Patching - Techniques and Materials."[C19] Categories reported are: patching procedures, materials, special equipment, experimental materials, and remarks. Some of the "materials" specified for patching are: high early strength concrete as well as asphalt mixes on portland cement concrete; surface spalls repaired with a modified epoxy; epoxies for small patches; plant mix and penetration patches on bituminous concrete; cracks filled with penetration emulsion or petrolastic sealing compound; high early strength concrete or regular mix concrete plus $CaCl_2$ accelerator; for full depth patches - a rich non-air entrained concrete; for full depth patches - 4 to 7 percent air entrained concrete; partial depth patches bonded with 1:1 sand-cement grout; rapid curing materials - Speed-Crete, Zip-Crete, Embeco, Express-Repair, Bond-Stress, Goof-Proof, Cybond polyester resin, Tri-Kote, Proco; concrete curing accelerators such as Sika-Set; 2 percent neoprene modified type RS-1 bituminous materials; for bridge decks - Shell Guard-Kote No. 140 or No. 250 epoxy, polysulfide epoxy

adhesive before portland cement concrete, paint patch area with epoxy coal tar and use an epoxy patching compound.

Not many other materials are mentioned under "Experimental Materials," but some of the remarks are interesting: work with Reclamite - a rejuvenating agent - is encouraging; epoxy mortar overlay is time saving but expensive; patching concrete with epoxies or latex or plastics is not very effective - regular portland cement concrete is better; super-set cements are expensive and not very durable; have tried coal tar epoxy (Guard-Kote) with generally acceptable results; have very little success with epoxies and quick-setting concretes.

5. Miscellaneous Highway and Runway Problems. Most of the items listed here are taken from titles and accompanying summaries in the NASA and DDC literature surveys made for us. In most cases, the literature was not obtained and credits are not given.

a. Surface friction. Skidding accidents on highways and runways can be reduced. Causes are worn tires, smooth surface, surface texture, locked wheels, and pilot technique. Many papers discuss the friction effect of runway grooves, especially in combination with water on the runways. An unbroken film of water on the runway can lead to "aquaplaning" or "hydroplaning." In addition to water, slush and ice affect runway traction and braking criteria.

b. Ice, snow and slush removal. The use of mechanical snow removal equipment, such as bladed snowplows, brush sweepers and rotary snowplows, is well known. To remove snow from inset airport runway lights, special

localized pavement heating systems are used. The removal of ice is more difficult, usually involving the use of chemicals, although sand is often used; and, in the U.S.S.R., a jet of hot air from the exhaust of a jet engine has been used. Chloride salts and deicing fluids are normally used, but these are notorious for their corrosive effects on metals and many attempts have been made to find effective but less corrosive substitutes. Some of these chemicals are De-Icer ID-1352B and crystal urea, or De-Icer ID-13 (Monsanto Chemical) and crystal urea carbamate.

Harris, et al,[C24] developed two candidate mixtures to melt snow, ice, and slush at temperatures as low as -10°F: the prime candidate = 75 percent K_3PO_4 plus 25 percent formamide; the second was $CaCl_2$ plus 1 percent by weight of Emulsifier STH (this had marked corrosion control). Application rate for melting at -10°F was 2 oz/sq ft. At the most, this had slight spalling effect on concrete.

Russian chemists[D7] have developed a de-icing powder, a binary salt of calcium nitrate and carbamide, known as NKM Compound, which does not corrode metals nor attack the road surface. First applications in areas with temperatures to -4°F were successful. A liquid NKM is produced for fighting the icing of ships and the freezing of ores and building materials. Both types were to go on the market in 1968.

c. High temperature jet blast. It was indicated earlier that a slurry seal coat was removed due to the concentrated jet blast[C17] and that the blast from a P.1127 made holes in asphalt during VTOL's.[A8] The direct exhaust of an afterburning J85-GE-5 turbojet engine was used to evaluate "Rapid Site."[A7]

Mitchell and Wheery[C3] used a YJ85-GE-3 turbojet engine to test the effect of jet exhaust impingement on soil, concrete, a sand-dirt-gravel mixture, and soil covered with landing mats. The velocities and temperatures of the exhaust gas at the impingement point were in the order of 425 to 1800 ft/sec and 450 to 1300°F with the nozzle height ranging from 3 to 6 ft. The results indicate that: unprepared surfaces are not usable for the ranges tested; soil covered with landing mats could be used on a limited basis; concrete probably could be used for an indefinite period; engine damage would result over sand and gravel mix; asphalt would be damaged; and there is danger to ground personnel due to flying objects, even over concrete.

Tomita and Well[B32] heated cubes made from hardened cement paste from ambient temperatures to temperatures from 1000°F to 1800°F at rates varying from 8 to 14°F per second. Some of the significant findings were: heating to 1000-1800°F caused a decrease in compressive strength; the heating rate had no appreciable effect; in general, heated calcium aluminate cement cubes yielded a lower average compressive strength than did heated portland cement cubes, but the rate of decrease in compressive strength with increase in maximum temperature was lower for the calcium aluminate cubes than for the portland cement cubes; increase in curing and drying from 8 to 29 days had no appreciable effect on compressive strength but 57 days curing and drying gave a lower rate of decrease in compressive strength with increase in maximum temperature; all heated cubes cracked and some showed spalling damage. The main conclusion was that cement paste and aggregate should be as dry as possible before being subjected to high thermal shock conditions.

d. D-cracking.(C13) D-cracking is a form of disintegration characterized by the successive formation of a series of fine cracks at rather close intervals paralleling edges, joints, and cracks, and usually curving across slab corners. The initial cracks form very close to slab edges and additional cracks progressively develop, each a little farther from the edge than the preceding one. D-cracking has been found to be limited, mainly to an area in the central part of the country which has moderately cold weather. There is no D-cracking in airfield pavements located in areas that have mild weather and very little D-cracking in northern areas which have very cold weather. The evidence indicates that poor subgrade drainage, combined with a large number of freeze-thaw cycles, which occur in a moderately cold area, are contributing factors to the development of D-cracking.

Fulwider(C25) observed that the use of subsurface drainage lines had only a limited effect on frost heave and that design for similar unusual soil conditions should provide for full frost protection or employ other expedients such as insulation. (This may be applicable to D-cracking, also!)

e. Fog. Fog is a major problem in the use of many airports. Seeding with dry ice and cooling by vaporizing liquid propane are two materials studied to alleviate this problem.

f. Marking paints. Deterioration of white alkyd marking paint occurred on asphaltic runways at several military airfields in southern California. Oleoresinous phenolic varnish paint generally gave much better performance at these installations. Better service was

also received when all of the slurry seal, both damaged and undamaged, in the area to be painted was removed and replaced before restriping.(C26)

A study was made to determine the basic causes of lifting of slurry seal from asphaltic subgrade under strips of reflectorized airfield marking paint. Lifting was greater for double thickness than for single thickness stripes, especially for those with paint formulations containing chlorinated rubber. Paints with lower boiling solvents caused less lifting than those with higher boiling solvents. Oleoresinous paints generally caused more lifting than alkyd paints. Highly aromatic solvents compared to lower aromatic solvents caused more lifting in alkyd paints; less in oleoresinous paints. The addition of a small amount of carbon black reduced lifting with oleoresinous paints but had little effect in alkyd paints. There was somewhat more lifting with 12 in. than with 4 in. wide stripes.(C27)

As these two excerpts show, adhesion of marking paints is a continuous problem compounded by interactions with the various surfaces encountered in airfield (and in road) pavements.

g. Overrun protection. To prevent death of personnel and loss of aircraft due to overshooting the runway on takeoff or landing, the development of a completely satisfactory arresting device is being actively pursued. The use of arresting cables, especially on aircraft carriers, is well known. Various types have also been tried on airfields. Parachutes and nets have also been used. Bade(C28) tested the use of soft gravel and aerated concrete material of various sizes to safely decelerate aircraft. Probably the most promising solution,

the use of plastic foam, has just appeared in the literature (December 1970).(C23) A 3 ft bed of urea-formaldehyde foam, 1000 ft long, is applied to the end of the runway. This length of foam will safely stop a fully loaded plane traveling at about 150 mph. Foam with a compressive strength of 50 psi is soft enough not to damage the aircraft but is strong enough to support rescue vehicles.

h. Others. There are many other airport problems badly needing better solutions. Some of these problems are: fire protection - fuels, fueling, passenger loading; adhesives for camouflage, texturing surfaces, lane marking decals; joint and crack sealing and patching; runway lighting; all-weather landing systems - runway and on-board; noise control; accommodation.

6. Soil Stabilization. "Lessons Learned" reports(F1 to F12) from operations in South Vietnam show the continuing need for more effective and inexpensive methods for soil stabilization. AGARDograph 25(C2) states the same needs. The needs and, consequently, the best possible solutions are very diverse. Certain areas need reinforcement to carry foot and light vehicular traffic. Berms, revetments, roadway shoulders, ditches, etc., need protection against erosion by wind and water. Dust, especially bad during the dry season, is a flight hazard to aircraft and causes accelerated wear to all army vehicles and equipment. Personnel at Wright-Paterson AFB informed us that the hard, spherical character and fineness of some South Vietnam beach sands pose special problems in the moving of personnel and equipment across them.

Grass is probably the best solution for many cases, especially for dust control, but grass cannot be started in the dry season.[F2,F12] Peneprime, an asphaltic dust palliative, often cut with 25 percent of diesel fuel, is much used. Anhydrous salts such as $CaCl_2$ pose corrosion problems. One study[C29] to find a material for dust abatement and increased trafficability, with the requirement that the maximum amount used should not exceed 3 lb/sq yd, recommended a cationic emulsion of a solution of a thermoplastic polymer, a coumarone indene resin, and a polar oil. T-17 membrane has been used as a moisture barrier and dust cover.[F3]

Many of the quick-set cements and resins considered earlier[A1,A2] have been recommended as soil binders and surfacing materials. For a gun pad subbase, local red clay in dust form was mixed with local haul, bleached laterite and 5 to 10 percent cement.[F10] As asphalt cold mix cannot be used to patch potholes in asphaltic runways during the monsoon season.[F11] Concrete has to be used and this requires little or no traffic for 6 to 8 hours. The use of $CaCl_2$ can cut this required wait in half. One runway was constructed of 8 ft of select fill with a 3 in. cap of asphaltic concrete.[F1] A sand-asphalt seating layer about 2 in. thick is designed to provide a flexible stabilized seat for M8A1 matting.[F2] Clay mixed with 6 percent lime produced a CBR of over 20; clay mixed with 6 percent lime and 8 percent portland cement produced a CBR of over 80.[F2]

A study was made to determine the feasibility of stabilizing soils containing a high percentage of gypsum with lime and cement.[C9] The soil, from Perrin AFB, Texas, contained 74 percent gypsum ($CaSO_4 \cdot 2H_2O$), 13 percent quartz, and 13 percent clay materials (mostly kaolinite). All

material, except for some large pieces of alabaster, were finer than No. 4 sieve size. The natural soil, molded at 17.3, 18.5, 19.3 percent and 20.2-22.2 percent water, gave unconfined compressive strengths from 30.3 to 59.2 psi. When 3, 6, and 9 percent lime was admixed with the soil, a maximum strength of 129.5 psi was obtained for 9 percent lime and 61.9 psi with 3 percent lime. Admixtures of cement with the soil gave a maximum strength of 155.3 psi for 9 percent cement.

7. Evaluation Equipment. No attempt was made to research equipment used to test runways, roads and soils, etc. Only a few noticed in passing will be mentioned here.

ASTM Method D1883-67, "Standard Method of Test for Bearing Ratio of Laboratory Compacted Soils," sometimes called California Bearing Ratio (CBR), compares the penetration load of a test soil to that of a standard material. A specified penetration piston, 1.92 in. in diameter (3 sq in. in area) and over 4 in. in length, is forced into a compacted soil specimen at a rate of about 0.05 in./min to a depth of about 0.5 in. Corrections are made for surface irregularities, etc. Bearing ratio is usually based on corrected loads in psi for penetrations of 0.1 and 0.2 in. per the following:

$$CBR = \frac{\text{corrected load at 0.1 in., psi}}{\text{1000 psi}} \times 100$$

$$CBR = \frac{\text{corrected load at 0.2 in., psi}}{\text{1500 psi}} \times 100$$

If the value for 0.2 in. penetration is greater than the value for 0.1 in., rerun the test. If the second run confirms the first, use the larger number for 0.2 in. penetration. If bearing ratio values for 0.3, 0.4, or 0.5 in.

penetrations are desired, the standard loads are 1900, 2300, and 2600 psi, respectively.

For field use in obtaining approximate indications of soil strength, portable core penetrometers are available.[A2,A13] Even pocket penetrometers (Soiltest CL-700 and Soiltest CT-421) are available.[A1]

Terry[C14] proposed to develop instrumentation that would allow rapid evaluation of trafficability and load bearing capacity of roadways, airstrips, and compacted areas (snow and soil). A recording probe or penetrometer, to record resistance to penetration vs. depth, was developed. Two satisfactory models were tested: one was manually operated, the other power operated by a hydraulic power unit and cylinder.

Foundation Mechanics, Inc.[30] have developed the "Road Rater" for the nondestructive testing and evaluation of highway and runway pavements and bases. The unit uses a hydraulic vibration exciter. It can be mounted on a light panel truck and operated by the driver.

8. Cold Weather Construction. Fulwider and Stearman[D8] have prepared a bibliography on winter construction covering the period 1940 to 1967. The following divisions are made: other bibliographies; bridge and building construction; cold concrete; heating concrete aggregate; concrete, protection; concrete, theory and experiment; concreting; construction, general; costs; dam construction, drilling; earthwork and excavation techniques; equipment operation and care; excavating, blasting; excavating tools and machinery; excavation, trench; frozen ground, thawing; heating equipment; masonry and brickwork; railroad construction; road and airfield runway construction.

F. FROM "LESSONS LEARNED" IN SOUTH VIETMAN

Selected "Operation Reports"[F1-F12] covering the past three years in South Vietnam were obtained in the hope that some information would be forthcoming relative to the permanency of repairs made with quick-setting cements, such as Fast-Fix, during Vietnam's monsoons. This hope was not realized, but some indication of the need and use of quick-setting cements, and other related needs, was obtained. Some of these will be presented here. Some needs relative to soil stabilization were just discussed (Section III.E.6).

1. Facilities Using Expedient Surfacing Materials. Some of the varied constructions used in a combat zone wherein quick-setting cements and other surfacing materials are utilized: roads[F1,F8,F9]; airfields - runways, taxiways, turn around, and parking ramps[F8,F9,F10,F11]; heliport pads[F1,F7,F11]; revetments and berms[F1,F7,F9]; pads for pumps, cold storage chests, and artillery[F1,F2,F10]; fighting and living bunkers[F8,F10]; slabs for buildings[F9]; surface for maintenance facilities[F8]; drainage systems[F10,F12]; and sandbags[F3].

2. Soil Stabilizing and Surfacing Materials Used. Some of the materials most frequently used are: portland cement concrete[F1]; asphaltic or bituminous concrete[F1,F2,F6]; surface treatment of asphalt (usually DBST - double surface treatment of asphalt)[F2,F11]; peneprime (an asphaltic dust palliative)[D7]; graded aggregate shot with peneprime[F11], sand-cement[F2], soil-cement[F6,F10], sand-bituminous[F2], and clay-lime[F2]; M8A1 steel matting[F1,F2,F4,F8], PSP (pierced steel planing)[F3], and AM-2 matting[F5]; T-17 membrane[F3]; and mulching and grass seeding[F12].

3. Problems, Repair Techniques, Etc.

a. Airfields. A taxiway had deteriorated beyond normal repair as a result of moisture in the subgrade. A total of 1800 sq yd of deteriorated pavement, base, and subbase were removed to a depth of 8 ft and replaced with selected fill. The surface was finished with 3 in. of asphaltic concrete.(F1)

Several techniques were utilized: (1) a laterite base was installed, surface sealed with asphalt, with M8A1 turn arounds at each end; (2) surface was given a double bitumen surface treatment; (3) a sand-cement runway was upgraded by using asphalt stabilized sand overlayed with M8A1 matting; and (4) a bitumen-concrete runway was constructed.(F2)

T-17 membrane was originally designed as a moisture barrier and dust cover to be utilized in the construction of tactical landing strips over a plastic soil base with a CBR rating of 10 or greater. T-17 membrane has been utilized successfully as a C-130 unloading apron over a compacted rock base. Success was due to complete policing and brooming of all loose rock from the surface of the rock base plus the addition of a 3 in. sand cushion beneath the membrane. Use of the recommended non-skid compound on the membrane can result in a hole, under the stationary wheel, after one turn of a plane - the stuff is too good.(F3)

Due to excessive use and poor soil bearing conditions, the moment transfer ends on M8A1 matting break and fall out, especially with use by C-130 aircraft. Welding a 1/4 in. steel plate over the break sufficiently repairs the broken matting ends, covers sharp edges, and gives added strength to the matting.(F4) During installation, M8A1 matting must be tightly anchored along the sides of

the runway; otherwise, an excessively loose surface develops after repeated landings and takeoffs, resulting in increased pumping action on the subgrade.(F7)

The airfield was upgraded by installing a 2 in. base of soil-cement and finishing with an asphalt surface layer. In maintaining forward airfields, matting is removed, subgrade failures repaired, and the matting replaced or the existing surface sealed. Most forward airfields are not accessible by land and airlifting of needed equipment and personnel is frequently required.(F6)

The subbase was replaced with 3 in. and 1 1/2 in. crushed rock, compacted, and shot with peneprime. The airfield surface was finished with a double surface treatment of asphalt.(F11)

In patching asphalt runway potholes during the monsoon season, the use of a portland cement concrete mixture is all right if little or no traffic is expected for 6 to 8 hours. If the runway cannot be closed to traffic over 3 hours, the addition of $CaCl_2$ to the mix water, due to the chemically induced rise in temperature, will sufficiently accelerate the reaction. Asphalt cold mix cannot be used to patch the potholes because mmoisture prevents proper bonding of the aggregate.(F11)

One method used to patch asphalt with cold mix when you have a wet hole, but dry weather, otherwise, is to drive a very dry sand-cement mixture into the subbase with an air hammer and leave it to set up. The top 4 in. is then repaired with cold mix. These patches are holding well.(F11)

b. Heliports. M8A1 metal matting was laid over an asphalt sealed base.(F1) Failure of the dust cover over sand fill in helicopter revetments, due to air turbulence caused by the helicoper, makes for hazardous conditions.(F7)

c. Berms and revetments. Earth berms were built around M8A1 storage pads and around fuel tanks in a tank farm.(F1) Berms of sand, 9 ft high, were built for ammunition storage. The sides were protected with peneprime.(F7) Revetments, 765 ft long and 9 ft high, were constructed from laterite. M8A1 matting was used for the sides; the top was protected with a 3 in. concrete cap.(F9)

d. Sandbagging vehicles. Effective sandbagging decreases the number of personnel killed by mine explosions, but many people are still injured by sand and pieces of bag driven into the flesh of the sustained wounds. In tropical climates, especially, this provides the risk of rapid infection. Rubber carpeting, 1 in. thick, over the sandbags improves the protection, stopping stones, etc. Scraps of T-17 membrane or similar material are second choice.(F3)

e. Concrete placing. Pneumatic nail drivers are used for vibrating concrete. In finishing concrete, the surface is vibrated by attaching external concrete vibrators to each end of a 3 in. pipe that is long enough to span the pad. It is difficult to place large slabs of new concrete during periods of frequent rainfall. This problem was solved by erecting 25 ft x 50 ft canvas covered steel pipe frames over the freshly poured concrete. In buildings, the foundations are placed and the walls and roof installed. The floors can then be installed during inclement weather.(F3)

f.501 Llenepriming. Peneprime does not penetrate, dry, loose dust to anchor to the subgrade. By using water or a 25-75 diesel fuel-peneprime mixture, the dust layer was

settled and penetration to the subgrade was 100 percent. Subsequent applications of peneprime built up a good thick seal coat that lasts under heavy traffic and rain.[F11]

4. Miscellaneous. Most aggregate for concrete must be blasted from solid rock quarries and crushed.[F1]

One yard handled an average of 50,000 bags of cement per day.[F1]

The need for adequate soil bearing capacity for roads, airfields, and buildings constructed in the Delta has involved one engineer section in an extensive research program for clay-lime stabilization. A sand-bituminous seal coat under M8A1 matting is not adequate.[F2]

Some buildings are constructed with prefabricated concrete slabs.[F9]

IV. RANGE FINDING LABORATORY TEST PROGRAM
Latex Modified Fast-Fix C-1 Cement

A. GENERAL

This section provides the detailed information on the laboratory program to evaluate the effect of latexes on the structural and durability properties of Fast-Fix C-1 cement.

B. MATERIALS

The cement used throughout the laboratory program is Fast-Fix C-1 as manufactured by The Western Company and obtained from the USAR Waterways Experiment Station, Vicksburg, Mississippi. The latexes used to modify the Fast-Fix C-1 cement are either Dow Latex 460, a styrene-butadiene latex, or Dow Latex 464, a vinylidene chloride-vinyl chloride-acrylic ester latex, as manufactured by The Dow Chemical Company, Midland, Michigan. The latexes are formulated prior to use with Antifoam B, a product of The Dow Corning Corporation, to control the air content of the modified cements.

The tensile splitting samples were prepared using a 6A Tile Stone obtained from Fisher Sand and Gravel, Midland, Michigan.

C. TEST PROGRAM

The Fast-Fix C-1 concrete and neat paste containing no latex or other additives was used as the control throughout the laboratory test program. The Dow Latex 460 was evaluated at 10 and 15 percent polymer solids based on the weight of the cement. Dow Latex 464 was evaluated at 15 and 20 percent polymer solids based on the weight of the cement. These are the normal levels at which these two latexes are used in

portland cement mortars and concrete. In all of the cement systems, water was added to produce a constant viscosity as measured on a Brabender Visco-Corder. Initial test results indicated that the latex levels were too high for use in the Fast-Fix C-1 cement. An exploratory program was conducted to find out if there is an optimum level of latex for the modification of the Fast-Fix C-1 cement. The program indicated that 4 percent Dow Latex 464, solids based on the weight of the cement, produced optimum results with latex modification; therefore, this latex modified cement system was included in the program.

The following tests and test methods were used to evaluate the effect of latexes on the properties of Fast-Fix C-1 cement:

(1) Compressive Strength - ASTM C-109

(2) Tensile Strength - ASTM C-190

(3) Flexural Strength and Elastic Modulus in Bending - ASTM C-256

(4) Splitting Tensile Strength - ASTM C-496

(5) Shear Bond Strength to Concrete - Dow Method

(6) Freeze-Thaw Resistance of 2 inch Cubes - ASTM C-290

The test samples were cast and cured in a constant temperature and humidity room set at 73°F and 50 percent relative humidity. The original program required the demolding of the test specimens in 20 to 25 minutes and conducting the first tests 30 minutes after the samples were

made. In most cases the test specimens did not have sufficient strength to remove them from the molds in this time. Therefore, this test schedule was eliminated and replaced by the following procedure: the test specimens were removed from the molds as soon as possible, 30 to 45 minutes, and tested at 1 hour, 1 day, and 28 days cure. All tests were run in triplicate unless otherwise noted.

D. TEST RESULTS

1. Formulations. The six Fast-Fix C-1 cement formulations are lisetd in Table XIXA. In addition, the formulations evaluated in the program to optimize the latex levels are listed in Table XIXB. The water to cement ratio in all of the formulations was arrived at by laboratory experimentation to obtain a viscosity equivalent to that of the control mix (#1) based on a water to cement ratio of 0.30 for the control.

2. Compressive Strength. The results of the compressive strength tests on the 2 in. cubes are listed in Table XX. The latex mixes, numbers 2 through 5, do not exhibit a compressive strength equal to the control mix, number 1. The lower level latex mixes, numbers 2 and 4, have higher strength values than the higher latex mixes, 3 and 5. Mix number 6 containing 4 percent Dow Latex 464 is stronger than the control by 5.2 percent at 1 day and 6.9 percent after 28 days cure; however, after 1 hour cure it is 10.1 percent weaker than the control indicating a slight retardation in the rate of gain of the early strength.

TABLE XIXA

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT FORMULATIONS

Formulations*	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Fast-Fix C-1 Cement	100	100	100	100	100	100
Water	30	13	6.5	9	3.3	23
Dow Latex 460**	--	20	30	--	--	--
Dow Latex 464**	--	--	--	30	40	8
Water/Cement Ratio	0.30/1	0.23/1	0.22/1	0.24/1	0.23/1	0.27/1
Latex Solids/ Cement Ratio	--	0.10/1	0.15/1	0.15/1	0.20/1	0.04/1
Viscosity***	240	240	270	240	260	190

*Mix proportions are parts by weight

**Contains 0.4% Antifoam B (active silicone based on weight of polymer solids)

***Brabender Visco-Corder, 25 rpm, 125 cmg Torque Spring

TABLE XIXB

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT FORMULATIONS

Formulations*	Mix 7	Mix 8	Mix 6	Mix 9
Fast-Fix C-1 Cement	100	100	100	100
Water	25.1	20.1	23	28.1
Dow Latex 460**	6	--	--	--
Dow Latex 464**	--	12	8	4
Water/Cement Ratio	0.28/1	0.26/1	0.27/1	0.30/1
Latex Solids/Cement Ratio	0.03/1	0.06/1	0.04/1	0.02/1
Viscosity**	140	210	190	140

*Mix properties are parts by weight

**Contains 0.4% Antifoam B (active silicone - based on the weight of polymer solids)

***Brabender Visco-Corder, 25 rpm, 125 cmg Torque Spring

TABLE XX

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
COMPRESSIVE STRENGTHS

Compressive Strength, psi	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
1/2 hour	137	--	--	--	--	--
1 hour	3040	661	164	2200	2080	2740
1 day	4230	2920	2010	3100	2580	4450
28 days	7920	5040	3190	5640	4540	8460

3. Tensile Strength. The results of the tensile strength tests on the one inch thick figure eight briquette are listed in Table XXI. The latexes slightly depress the 1 hour tensile strength of the Fast-Fix C-1 cement. One day and 28 day strengths are about equal to the control when modified with 10 percent Dow Latex 460 or 20 percent Dow Latex 464.

TABLE XXI

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
TENSILE STRENGTHS

Tensile Strength, psi	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
1 hour	271	242	34	208	219	87
1 day	370	335	262	388	380	350
28 days	742	745	592	662	698	637

4. Flexural Strength and Elastic Modulus in Bending. The flexural properties were obtained by testing flexural bars 1/2 in. thick by 2 in. wide over a test span of 10 in. The loading force was applied at the center point. The

flexural strength was computed from Eqn. 1 and the elastic modulus in bending by Eqn. 2. The results are listed in Tables XXIIA and XXIIB.

Equation 1

$$R = \frac{3WL}{2\,bh^2}$$

Equation 2

$$E = \frac{WL^3}{4\,sbh^3}$$

R = modulus of rupture in pounds per square inch

E = elastic modulus in bending in pounds per square inch

W = maximum applied load in pounds

L = test span in inches

b = width of specimen in inches

h = average thickness of specimen in inches, to the nearest 0.01 inch

s = mid-point deflection under maximum load in inches

Dow Latex 460 and Dow Latex 464 at 15 percent and 20 percent modifications of the Fast-Fix C-1 cement lower the flexural strength and the elastic modulus of the cured mortar. Dow Latex 464 at 4 percent latex level increases the flexural strength of the Fast-Fix C-1 cement by 25 percent after 1 day cure and by 19 percent after 28 days cure. The 1 hour strength is lower than the control, again indicating a slight reduction of the rate of early strength gain of the latex modified cement.

TABLE XXIIA

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
FLEXURAL STRENGTHS AND MODULI

Flexural Strength-psi	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Modulus of Rupture (R)						
1 hour	717	--	--	272	373	439
1 day	870	741	530	791	706	1090
28 days	2220	1560	1300	2030	1890	2640
Elastic Modulus (E)						
1 hour	1.20×10^6	--	--	0.49×10^6	0.67×10^6	0.68×10^6
1 day	1.82×10^6	1.22×10^6	0.93×10^6	0.94×10^6	1.06×10^6	1.78×10^6
28 days	2.56×10^6	1.75×10^6	1.37×10^6	1.85×10^6	1.55×10^6	2.51×10^6

TABLE XXIIB

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
FLEXURAL STRENGTHS AND MODULI

Flexural Strength-psi	Mix 7	Mix 8	Mix 6	Mix 9
Modulus of Rupture (R)				
1 hour	59	522	439	302
1 day	786	965	1090	852
28 days	1980	2270	2670	2220
Elastic Modulus (E)				
1 hour	0.09×10^6	0.88×10^6	0.68×10^6	0.50×10^6
1 day	1.55×10^6	1.60×10^6	1.78×10^6	1.69×10^6
28 days	2.00×10^6	2.38×10^6	2.51×10^6	2.27×10^6

All the latex modified cements at high latex levels (Mixes 2 and 5) are considerably more flexible than the control. The Dow Latex 464 modified cement (Mix 6) at the 4 percent level has equal flexural properties in comparison to the unmodified Fast-Fix C-1 cement.

5. Splitting Tensile Strength. Splitting tensile strengths were obtained by testing 4 in. concrete test samples. The samples were prepared by filling the forms with dry 6A stone. The cement pastes were then prepared and poured over the stone, allowing the paste to percolate through the stones to fill the voids and cement the stones together.

The 6A stone utilized in this test conforms to the gradation requirements of the Michigan State Highway Department "Grading Requirements for Coarse Aggregates for Surfacing Aggregates" which specifies the following screen analysis:

Sieve Size	Percent Passing
1 1/2 inch	100
1 inch	95 - 100
1/2 inch	30 - 60
No. 4	0 - 8

The results of the tensile splitting tests are listed in Table XXIII. The tensile splitting strengths were calculated from the standard Eqn. 3.

TABLE XXIII

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
SPLITTING TENSILE STRENGTHS

Splitting Tensile Strength - psi* (4" x 8" cylinders)	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
1 day	243	175	176	218	209	282
28 days	441	370	297	448	440	439
Aggregate Fractured						
1 day	5%	5%	2%	5%	2%	5%
28 days	11%	9%	5%	16%	9%	13%

*Average of 2 tests

Equation 3

$$T = \frac{2W}{\pi\, ld}$$

T = splitting tensile strength in pounds per square inch

W = maximum applied load in pounds

l = cylinder length in inches

d = diameter in inches

The Dow Latex 460 modified concrete exhibited a reduced splitting tensile strength in comparison to the unmodified control. The Dow Latex 464 modified concretes were about equal to the control except that the 4 percent latex level modified concrete specimens showed a 16 percent increase in strength after one day cure. This is contrary

to the results of previous test results and may be due to the absorption of water by the dry aggregate resulting in an accelerated 1 day strength in comparison to the control samples.

6. Shear Bond Strength. This test method was developed by The Dow Chemical Company to obtain a more reliable correlation between bond strength values obtained in the laboratory and those obtained in actual field exp   ence. The test method directly correlates the bond strength cured cement overlayments of 1/2 in. or more thickness to concrete.

Concrete cylinders 3 3/8 in. in diameter by 6 in. in length are made and allowed to cure for 28 days; the first 7 days cure is in total water immersion. The cylinders must have a minimum compressive strength after 28 days cure of 5000 psi.

After the cylinders have cured, one end is wet ground on a belt sander using a No. 40 emery grit sanding belt to obtain a smooth surface. Aggregate in the concrete must be exposed during grinding and care must be taken not to overheat the concrete surface.

The sanded surface is cleaned of all foreign matter and dampened with water. It is then capped with a 1 in. thick layer of the surfacing mortar to be evaluated following standard sample preparation procedures as listed in ASTM designation C-109. The surfacing mortar is allowed to cure under the conditions described in Section IV.C. until tested.

To determine the actual shear-bond strength, the concrete cylinder is inserted into a heavy walled steel sleeve which has been securely fastened to the base of the testing machine. The 1 in. mortar cap is allowed to extend out beyond the edge of the metal sleeve.

A constantly increasing force is applied to the mortar cap by a steel ram placed on the mortar cap perpendicular to the main axis of the cylinder. The shear bond strength is determined by Eqn. 4.

Equation 4

$$S = \frac{W}{A}$$

S = shear bond strength in pounds per square inch

W = maximal applied load in pounds

A = cross sectional area of the cylinder face in square inches

Physical observations should be made of the failure; i.e. at the bond interface, in the mortar cap or in the base concrete cylinder.

The test results of the shear bond strengths are listed in Table XXIV. All the test samples failed at the bond interface except for the 28 day cured samples made with Mix 5 containing 20 percent Dow Latex 464. Two of these samples yielded with 50 percent of the failure in the base cylinder and the remaining failure being at the bond interface.

TABLE XXIV

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT SHEAR BOND STRENGTHS

Shear Bond Strengh psi	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
1 day	11.9	26	48	53	87	51
28 days	24.5	104	265	332	418	102

The latex modified Fast-Fix C-1 cement exhibited a 4 to 17 fold increase in bond strength over the unmodified control sample after 28 days cure. This fact could be very significant in medium or long range serviceability of rapid repair mortars over partially damaged concrete (surface damage in which the basic structural integrity of the concrete is still preserved).

The basic improvement in bond strength of latex modified cement mortar has been recognized for many years in portland cement and is also a very strong point in the modification of Fast-Fix C-1 cement. This fact may be valuable in the use of Fast-Fix C-1 cement in making rapid, permanent repairs to all types of concrete structures.

7. Freeze-Thaw Resistance. The freeze-thaw resistance of 2 in. cubes was determined on the six basic formulations as well as three additional formulations listed in Table XIXB used to determine the optimum latex level for modification of Fast-Fix C-1 cement.

All the test specimens were aged 28 days at 73°F and 50 percent relative humidity prior to evaluating their freeze-thaw durability. The samples were then immersed in water to obtain a saturated condition. The 24 hour water absorption obtained from this preconditioning is recorded in Table XXV. All the latex modified samples absorb considerably less water than the control samples.

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TABLE XXV

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
WATER ABSORPTION

24 Hour Water Absorption-%	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
28 days*	7.88	2.51	0.85	1.48	1.55	3.58

	Mix 7	Mix 8	Mix 6	Mix 9
28 days*	4.41	2.59	3.58	5.60

*Test samples cured 28 days at 73°F and 50% relative humidity, then immersed in water 24 hours at 73°F.

The first 21 freeze-thaw cycles were run using a "slow" cyclic procedure. The samples were frozen overnight (16 hours) at 0°F and thawed during the day (8 hours) at 73°F. Visual observations and weight measurements were made after 1, 3, 7, 10, 16, and 21 cycles. From 21 through 117 cycles the samples were placed in a Conrad accelerated freeze-thaw chamber under conditions outlined in ASTM designation C-290. The results of these tests are recorded in Tables XXVIA and XXVIB. These tables record both the percent weight gained or lost under freeze-thaw cycling in water and the surface scale rating at the end of a given number of cycles. The surface scale rating is a numerical rating system from 0 to 5 which rates the extent and depth of scaling. The numerical values are defined as follows:

0 = no scaling
1 = very slight scaling
2 = slight to moderate scaling
3 = moderate scaling
4 = moderate to bad scaling
5 = severe scaling

A series of control samples that have deteriorated to the degree that they correspond to the numerical rating system are maintained as standards.

Latexes greatly improve the freeze-thaw resistance of Fast-Fix C-1 cement. The higher percentage of latex produces the best freeze-thaw protection; however, low percentages of latex (4 percent in Mix 6) still produce a marked improvement in the freeze-thaw resistance properties.

Graph I illustrates the percent weight gained or lost listed in Tables XXVIA and XXVIB. This gives a visual picture of the improved durability of the Fast-Fix C-1 cement modified with latex.

E. CONCLUSIONS

Dow Latexes 460 and 464 are not recommended for modification of Fast-Fix C-1 cement for the rapid repair of bomb-damaged runways. The latexes do not increase the strength of the Fast-Fix C-1 cement enough to allow any significant reduction in the concrete slab thickness. The latexes increase the cost of the resulting concrete as well as adding one additional material to be mixed into the concrete. A significant increase in strength would have overcome these objections by reducing the volume of concrete required for the repair of a bomb crater. Cost savings would have been realized from faster placement time and less expensive mixing equipment as well as lower material transportation costs. These types of savings have been realized for many years with the use of latexes for the modification of portland cement systems.

The increased bond strength and freeze-thaw durability of latex modified Fast-Fix C-1 cement might justify the use of the latexes in repairing surface damage of structurally sound concrete.

TABLE XXVIA

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
FREEZE-THAW RESISTANCE

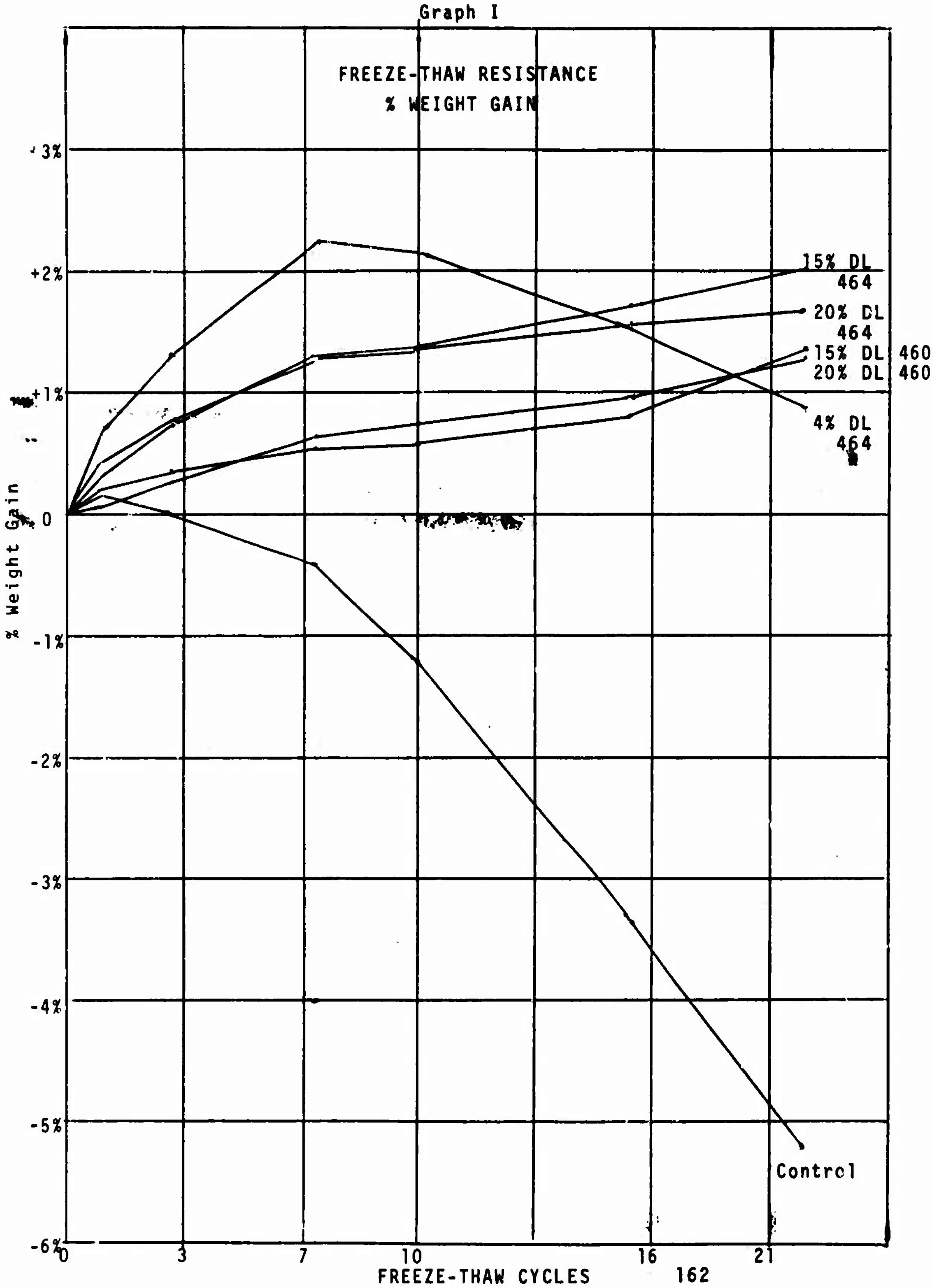
Freeze-Thaw Resistance-%	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
1 cycle	+0.18	+0.08	+0.21	+0.32	+0.32	+0.69
3 cycles	0	+0.29	+0.34	+0.75	+0.76	+1.30
7 cycles	-0.43	+0.62	+0.55	+1.30	+1.32	+2.23
10 cycles	-1.22	+0.71	+0.59	+1.38	+1.36	+2.15
16 cycles	-3.38	+0.96	+0.80	+1.70	+1.56	+1.54
21 cycles	-5.22	+1.29	+1.34	+2.01	+1.68	+0.85
117 cycles	Disintegrated	-0.66	-0.25	-3.47	-3.12	-10.44
Surface Scale Rating						
1 cycle	0	0	0	0	0	0
3 cycles	1	0	0	0	0	0
7 cycles	3	1	1	1	1	2
10 cycles	5	1	1	1	1	3
16 cycles	5+	3	1	1	1	4
21 cycles	5+	3	1	2	1	5
117 cycles	Disintegrated	5+	5+	5+	5+	5+

TABLE XXVIB

LATEX MODIFIED FAST-FIX C-1 RAPID SETTING CEMENT
FREEZE-THAW RESISTANCE

Freeze-Thaw Resistance-%	Mix 7	Mix 8	Mix 6	Mix 9
1 cycle	+0.33	+0.33	+0.69	+0.70
3 cycles	+0.70	+0.62	+1.30	+0.94
7 cycles	+0.91	+1.00	+2.23	+0.39
10 cycles	+0.62	+0.92	+2.15	-0.40
16 cycles	-0.41	+0.50	+1.54	-2.29
21 cycles	-1.33	+0.06	+0.85	-3.39
117 cycles	-6.84	-6.82	-10.44	-10.43
Surface Scale Rating				
1 cycle	0	0	0	0
3 cycles	0	0	0	1
7 cycles	3	2	2	4
10 cycles	4	3	3	5
16 cycles	5	4	4	5+
21 cycles	5+	5	5	5+
117 cycles	5+	5+	5+	5+

Graph I


FREEZE-THAW RESISTANCE
% WEIGHT GAIN
+3%
+2%
+1%
0
-1%
-2%
-3%
-4%
-5%
-6%
% Weight Gain
15% DL 464
20% DL 464
15% DL 460
20% DL 460
4% DL 464
Control
0
3
7
10
16
21
FREEZE-THAW CYCLES

V. TRADE OFF STUDY AND FOLLOW ON PLAN

The results of the laboratory program do not indicate any advantageous reasons to incorporate latex into the Fast-Fix C-1 cement for use in the Rapid Repair of Bomb-Damaged Runways. Latexes will result in increased cost, more complex mixing procedures and no significant saving in the quantity of Fast-Fix C-1 required.

Because of the generally negative results of the laboratory work, we do not recommend additional work in the area of latex modified gypsum cement systems. Therefore, we do not recommend any Follow On Plan along this line of research.

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To assist in handling the number and variety of references cited, this bibliography has been divided into several sections. This division is very approximate; if a reference is listed in an earlier section, it is not listed in a later one where it may more appropriately belong.

Glossary

The following abbreviations have been used in this bibliography:

AEWES	U. S. Army Engineer Waterways Experiment Station Corps of Engineers Vicksburg, Mississippi 39180
AFAPL	Air Force Aero Propulsion Laboratory Air Force Systems Command (unless otherwise noted) Wright-Patterson Air Force Base, Ohio 45433
AFML	Air Force Materials Laboratory Research and Technology Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433
AFWL	Air Force Weapons Laboratory Kirkland Air Force Base, New Mexico 87417
APGC	Air Proving Ground Center Eglin Air Force Base, Florida 32542
CRREL	Cold Regions Research and Engineering Laboratory U. S. Army Materiel Command Terrestrial Sciences Center Hanover, New Hampshire 03755
NAEC	Naval Air Engineering Center Philadelphia, Pennsylvania 19112
NCEL	U. S. Naval Civil Engineering Laboratory Port Hueneme, California 93041
NOL	U. S. Naval Ordnance Laboratory Indian Head, Maryland 20640
ORD Labs.	Ohio River Division Laboratories U. S. Army Engineer Division, Ohio River Corps of Engineers Cincinnati, Ohio 45200
TR	Technical Report
USNAF	U. S. Naval Air Field
USNAS	U. S. Naval Air Station
USNOLF	U. S. Naval Outlying Field

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Dow Chemical Company Midland, Michigan	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

LATEX MODIFICATION OF FAST-FIX C-1 CEMENT FOR THE RAPID REPAIR OF BOMB-DAMAGED RUNWAYS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report

5. AUTHOR(S) (First name, middle initial, last name)

R. D. Eash
G. M. Hart

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1971	198	~~142~~ 138

8a. CONTRACT OR GRANT NO. DACA 39-70-C-0022	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) U. S. Army Engineer Waterways Experiment Station Contract Report C-71-1
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Report prepared under contract with U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi	U. S. Air Force, Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This report consists, essentially, of two parts: a state-of-the-art review and laboratory testing of the effects of adding two Dow polymeric latexes to "Fast-Fix C-1". The state-of-the-art review covers several basic studies in which many materials, both organic and inorganic, were investigated. The study was then focused on the study of fast-setting inorganic cements and methods to obtain fast setting. Miscellaneous cement technology, such as methods to obtain high strength concrete, silicate concrete, and cementitious ceramic materials, are also covered. The state-of-the-art review also has a section indicating areas in which fast-setting cements can serve and the requirements placed on this service. Topics covered are runway design, pavement requirements, pavement evaluation, surface repair, and cold weather construction. In the lab study, two polymeric latexes, Dow Latex 460 and Dow Latex 464, were incorporated at selected concentrations in Fast-Fix C-1 mortars. Tests were conducted to determine freeze-thaw durability, tensile strength, compressive strength, flexural strength, and shear bond. All latex concentrations improved bond strength and freeze-thaw durability and decreased 24-hour water absorption. All concentrations tended to retard set and early strength gain. Low concentrations (4%) of Latex 464 produced a modest improvement in compressive and flexural strengths, but no change in the elastic modulus. Due to the added expense and more complicated mixing procedure, the use of latexes to modify Fast-Fix C-1 cement for the rapid repair of bomb-damaged runways is not recommended.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cements						
Fast-fix C-1 cement						
Latex						
Rapid construction						
Runway repairs						

Unclassified
Security Classification